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Trend in non-destructive quality inspections for oil palm fresh fruits bunch in Indonesia

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Abstract

The quality of oil palm Fresh Fruits Bunch (FFB) is a major key within oil palm processing that strongly influence the products grade and quantity, Crude Palm Oil (CPO) in particular. The features of the FFB can be measured, among other, by its ripeness stages, oil content, free fatty acid level, and carotene content. Grading aimed to ensure only prime FFB enter the processing. However, human visual grading provides great challenge to achieve ideal result. Meanwhile, recent developments have enabled the application of precision technologies and automation to grade the FFB using Non-destructive Evaluation based on machine vision and spectrophotometry principle. This paper reviews the development and application of both technologies in Indonesia for quality inspection of oil palm FFB.

Introduction

Following the 1999 booming, the plantation area of oil palm in Indonesia had increased by more than tenfold in the last 15 years (Ditjenbun, 2014). As early as 2006, Indonesia surpasses other countries and became the major producer of oil palm fresh fruits bunch (FFB), and subsequently its processing and derivative products (World Growth, 2011). The growth and progress of oil palm industry in Indonesia achieved through the massive expansion of oil palm plantation, especially in major islands (Figure 1), such as Sumatra, Kalimantan, Sulawesi and Papua (BKPM, 2014). Correspondingly, the forest area in these locations were dwindling, thus compromising the ecosystems and environmental conditions in mentioned area (WALHI. 2015).

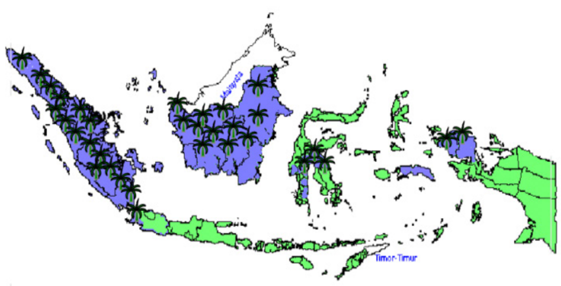

Figure 1. Oil palm plantation in Indonesia and expansion area (trees) (BKPM, 2014)

In order to prevent further deforestations (Figure 2), the Indonesian government issued a moratorium that prohibits further expansion of oil palm plantations in Indonesia (Setneg, 2013). In addition, the government also limits the land ownerships of an oil palm holding company to 100,000 hectares (BPN, 2013). Consequently, since 2014, the rate of growth of the oil palm industry in Indonesia starting to slowdown. Therefore, it is necessary to find other ways to increase the productivity of oil palm industry in Indonesia.

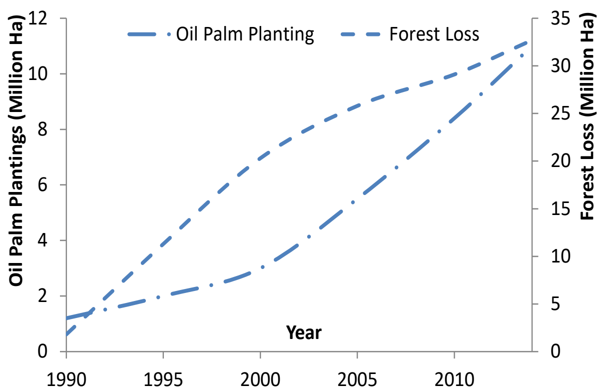

Figure 2. Oil palm planting and forest loss in Indonesia, 1990-2008.

Crop productivity, e.g. oil palm, is determined from the number of fresh fruits bunch (FFB) harvested from a single tree, as well as the amount

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of oil contained in the bunch (Risza, 1994; Mangoensoekarjo and Semangun, 2005). In addition, the quality of oil in the FFB determined by its free fatty acid (FFA) level (Makky *et al*., 2014), which highly dependent on the FFB ripeness upon harvest (Makky and Soni, 2014). Increasing the productivity of oil palm industry in Indonesia, can be done, among others, by raising the palm oil yield per square plantation area, which is still lagging behind other palm oil producer country, such as Malaysia (DMS, 2012). Another approach is by improving the quality of crude palm oil (CPO) produced by mills to achieve better selling price in world markets (Beddu, 2014).

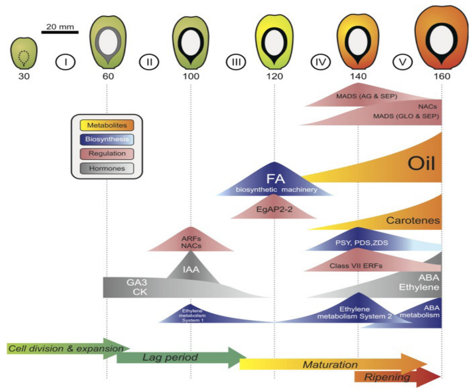

Figure 3. Scheme representing the major events that occur during the phases of mesocarp development (Tranbarger, 2011)

The oil palm FFB starts to develop immediately after the pollination take place. In general, it takes approximately 180 days for FFB to become completely mature and ripe, in order to be ready for harvest (Figure 3) (Tranbarger *et al*., 2011). In todays practice, harvesting the FFB in the plantation commonly done based on scheduled set by the plantation company management. The applications of this harvest practice produced susceptibility, where non-fully ripe FFB also harvested as well, in order to follow the schedule. To minimize this kind of mistake when harvesting performed, most palm plantations in Indonesia conducted harvesting methods based on assessments, through observation of FFB color, or by calculating the number of detached fruitlets on the area around the base of tree trunk. These methods cannot be implemented properly, due to several shortcomings. The first is the differences in color perception to the human eye when observation performed. Human color perception strongly influenced by emotional condition and fitness of the observer (Makky *et al*., 2004). In addition, some oil palm cultivars have similar FFB appearance between the ripe and the non-ripe fruits. The other method, through counting the number of detached fruitlets, also less accurate, and cannot be used solely to determine that the corresponding FFB should be harvested. The fruitlets can be detached from the FFB before ripening process took place due to other reasons, such as pest or animal attack, as well as FFB exposure to heavy rain or gale (Makky and Soni, 2013). Therefore, to date, incorrect harvest practice still take placed in Indonesia, and lead to the entrainment of substandard FFB in the processing at palm mills, which contribute to 10-15% production loss (Makky, 2016).

Entrainment of substandard FFB in to the processing mills will inflict revenue loss to the corresponding company, due to the quality degradation of CPO produced. In order to prevent this loss, the FFB should be harvest at the prime condition and fully ripe (Makky *et al*., 2012). Another way is by ensuring only prime FFB enter the processing process in mills, by means of sorting and grading. In oil palm mills and plantation, FFB sorting actually had been carried out manually by labors. The processes highly depend on the skills and experiences of the graders to identify and segregate substandard FFB, based on its appearances. None the less, similar to the harvest practices, this sorting method has limitations, mainly because it requires a lot of man power, while the process itself is slow and arduous. It results in less objective assessment, making the overall sorting result inconsistent and less accurate (Makky *et al*., 2012). Furthermore, the process made FFB susceptible to damage, which consequently will downgrade the bunch quality (Hadi *et al*., 2009). Based on this circumstance, systems which can perform accurate and consistent nondestructive quality determination for oil palm FFB were needed to be implemented in oil palm plantations and mills in Indonesia.

Along with the progress and advancement of technology, nondestructive evaluation (NDE) techniques have been able to be used for agricultural products quality assessment (Manickavasagan and Jayasuriya, 2014). Likewise, NDE techniques also have been utilized for quality inspections and ripeness determination for oil palm FFB before and after harvest took place (Abdullah *et al*., 2001; Ishak and Hudzari, 2010; Saeed *et al*., 2012; Cherie *et al*., 2015a, 2015b). The evaluation and quality assessment aimed to prevent substandard FFB enter the processing line in oil palm mills. In Indonesia, similar technology development has allowed the implementation of NDE for FFB quality assessments. The NDE techniques in Indonesia generally based on the machine vision technology (Makky *et al*., 2004, 2012, 2012, 2014; Cherie *et al*; 2012, 2015a, 2015b; Makky and Soni, 2013a, 2013b; Makky,

2016) and spectroscopy (Thoriq *et al*., 2012; Makky *et al*., 2012; Makky and Soni, 2014). This paper discussed the developments and applications of NDE techniques in Indonesia for FFB quality assessment during harvesting and grading.

Materials and Methods

NDE technique for identification and locating ripe FFB on plants for harvest using stereo 3D machine vision

In this method (Makky *et al*., 2004), a pair of digital cameras (EasyShare CX7330, Kodak, USA) placed side by side, and distance between both camera lens center points was set at 90 mm. For observation and recording the FFB images, the stereo camera faced perpendicularly toward the oil palm trees under consideration. The cameras positioned in parallel to the high of FFB on tree, which become the object of observation. In order to obtain the best observation results, the stereo camera direction was set to the center of the tree trunk, horizontally facing the FFB cluster. The FFB images, recorded by the stereo camera, were then directly analyzed by the image processing software. The color and position information from the FFB images were extracted to determine its ripeness and distance from the camera. In the images, the ripe FFB segmented from other through thresholding process, where the value of red, green and blue (RGB) in each pixel was compared with reference values obtained from calibration. Similarly, the value of hue, saturation and intensity (HSI) in each pixel also compared with reference values from calibration. The RGB and HSI value in each pixel that meets reference values were considered as ripe FFB. Furthermore, morphological operation then performed by the image processing software to connect these pixels into one group hence considered as ripe FFB. The ripe FFB location then determined based on size of the pixel group, its tilts and orientation. Based on this information, the cutting point of FFB for harvest can be calculated. The information extracted from the image then fed into the control system, which subsequently activated the harvesting arm and direct the cutting blade onto the harvest position, in order to cut off the FFB from the tree. Therefore, the harvesting process can be done correctly.

Camera vision for FFB ripeness stages determination on plants to perform harvest prediction

In this NDE methods (Makky *et al*., 2012; Cherie *et al*., 2012, 2015a; Makky and Soni, 2013b) the harvest decision for FFB under consideration can be done through camera-vision observation. The system consist of a camera (EOS 600D, Canon, Japan) equipped with 2600mm focal point optical lens (Bushnell, USA), in order to produce high quality FFB image under 30 times magnification. For observation, the camera placed on a tripod, and directed facing towards FFBs on the plants. The lens is set so that the object fully visible in the camera screen. Before recording the image, the lens setting was adjusted, in order to magnify the object (FFB sample), until the camera's field of view cover a region of targeted FFB within an area of 125 x 125 mm. The camera's field of view setup intended to exclude other objects being recorded in the images. The recorded FFB images were then processed using image processing software, to retrieve color information in form of RGB and HSI color channels. Furthermore, the color ratio and index were calculated from the images, based on the RGB and HSI data. Models, developed to estimate the FFB ripeness and oil content based on color data, was used to predict the object's quality parameter (Makky *et al*., 2012; Cherie *et al*., 2012, 2015a, 2015b). The results determined whether the observed FFB is ready to be harvested or not.

Spectroscopy analysis for ripeness determination of intact FFB on plants in order to perform harvest decision

In this NDE technique, the method for determining the harvest of FFB is relatively similar with the previous one (No. 2). However, instead of using a camera, the inspections of FFB in this system were done by means of UV/VIS spectroscopy. The spectral measured reflected lights from FFB surface on plants, with the wavelengths taken into account ranging from 280 nm to 850 nm. A probe, coupled with a monocular (Bushnell, USA), provides 12 times magnification passing the focused reflected light from the FFB into the spectral. In order to assist the operator correctly aiming the probe toward the FFB, a laser pointer is placed in parallel to the monocular. The laser is activated upon directing the probe to the FFB. The laser light aimed to the center of the FFB surface, and subsequently switched off. Afterwards, the incoming light from the FFB that reach the probe surface was transmitted into the UV/Vis spectral through fiber optic. The spectrum and intensity of the incoming light subsequently measured by the spectral and the data feed into the computer. A model, developed to estimate the FFB ripeness, oil content and FFA, based on spectral data, was used to predict the FFB quality parameters. The results determined whether the observed FFB is ready to be harvested or not.

A FFB grading machine using photo-selective sensors

The prototype of this grading system was developed in 2007 and has been tested in the laboratory to perform FFB segregation based on its fruits color (Makky *et al*., 2008). The machine was designed to work in oil palm processing mills, and performed quality inspections of FFB samples, and subsequently segregated substandard FFB from the inline system. The machine consists of a platform; a conveyor belt; an inspection system; a grading mechanism and an electric motor as power source. The machine works by transporting FFBs through a single row of photo selective sensors, placed crosswise 100 cm above the conveyor. A series of LED lights, placed in parallel next to the sensors, illuminate the passing FFB. The reflected lights from the FFB surfaces irradiate the sensors, resulting changes of voltage in the sensor. An analog to digital converter (ADC) measured this voltage change in digital number, and provide the results for the microcontroller system (MCS). A threshold value was stored in the MCS memory, to compare the voltage in the sensor. The threshold value was obtained from the calibration, performed by passing several ripe and prime FFB under the sensors. The substandard FFB commonly have darker color, thus reflected less light to the sensor, resulting smaller voltage change in the sensors. Therefore, when a FFB has much lower voltage changes while being examined, the bunch considered as substandard and segregated from the processing line.

Automatic grading machine for oil Palm FFB based on camera vision

This system was developed based on further development of the previous grading machine mentioned earlier (Makky and Soni, 2013a; Makky *et al*., 2014). The fundamental differences were the type of sensors used for inspection and the application of automation in the system. An inspection chamber was introduced in this machine, in order to have high quality and color of the FFB images. In addition, the inspection chamber allows the recording of FFB images without affected by other light, i.e. sunlight. The grading machine, equipped with a conveyor belt, transported the FFB into the inspection chamber. A photo-sensitive sensor was placed inside the inspection chamber, and used to detect the presence of FFB in the inspection chamber. A laser emitter constantly emitted the sensor. When a FFB enter the inspection chamber, the light emitted the photo-sensitive sensor will be interrupted, thus triggers the microcontroller to stop the motor and conveyor belt for several moments, turning on the LED lights inside the inspection chamber, and subsequently send instruction to the computer to record FFB inside the chamber, using a digital camera, connected to the computer by an USB data lines. While the image inside the chamber was recorded three times, the grading mechanism at the end of the machine positioned itself, align to the inspection chamber. Afterwards, all three recorded images were directly processed by the image processing software which performed averaging, enhancement and segmentation in order to eliminate non-interest objects from the image, and extract the color information from the images, namely RGB, HSI, rgb, and ripeness index. Developed model use these color information data to predict the FFB quality parameters, namely ripeness, oil content and FFA. The FFB with estimated quality parameters below the standard will be segregated by the grading mechanism, to avoid the bunch entering processing line. The system operates automatically, however, loading the FFB onto the machine were still performed manually.

Low cost portable inspection system for oil palm FFB using camera-vision

Beside permanent grading system, inspection of the FFB quality could also be done in-situ using a portable inspection system (Makky *et al*., 2012; Makky, 2016). The portable systems allow FFB assessment to be carried out directly after harvest, by examining its quality properties. The FFB with substandard grade will not be transported to mills for processing; instead it will be sold directly to other mills with a discount prices. This portable inspection system comprised of an inspection chamber with LED as light source, a battery set to power the LED, and a digital camera connected to a portable computer. Image processing software was developed to analyze recorded FFB images. To perform assessment, the FFB sample was placed inside the inspection chamber, and then the lights were switched on, subsequently the FFB images recorded by the camera, placed on top of the chamber facing downward towards FFB. The recorded images was then transferred into the portable computer and processed by the image processing software. The program performed segmentation, and extract the color information from the image, in three color channels, namely RGB, HSI, and RGB index. Other color information, e.g. the ripeness index, also extracted from the image by the software. A developed model use these color information to estimate the ripeness, oil content, and FFA level of the FFB. The assessment results will determine whether the FFB should be transported to mill for processing, or sell as a second class product to other company.

Rapid portable inspection system for oil palm FFB using Vis/NIR spectroscopy

Another type of portable inspection system for oil palm FFB was developed using Vis/NIR spectral (Makky and Soni, 2014). The system works by measuring the reflectance of lights from the FFB surface within the visible (380-720nm) and near infrared (720-1100nm) spectrum. The system able to predict the ripeness, oil content, and FFA from the FFB under consideration, based on its spectral reflectance data. Since no image needs to be recorded, this system does not require an inspection chamber upon assessing the FFB. The FFB quality inspection performed by placing the probe perpendicularly to the fruits surface from the distance of 1 cm. a halogen lamp in the spectral transmitted the light to the probe tip through a fiber optic cable. The halogen light emitted through the probe illuminate the surface of fruits in the FFB, reflected back to the probe. The probe has two light pathways on its tip; the first functioned to pass the light from the halogen lamp to the surface of the object, while the second path serves to transmit the reflected light from the object to the light sensor in the spectral. For quality assessment, the surface of the FFB was measured by the Vis/NIR spectral on three points, all along the equator of the bunch, with evenly distributed distance. The spectral data from measurements were then preprocessed to remove noise. The data then incorporated into model, developed to predict the ripeness, oil content and FFA of the FFB. Similar to the previous portable inspection system, the quality assessment results from this system will determine whether the FFB should be transported to mill for processing, or sell as a second class product to other company.

Results and Discussion

From all seven NDE techniques described in the previous section, the methods used for FFB quality assessment, that have been developed in Indonesia, can be grouped into three categories. The first NDE category for FFB quality assessment employed the techniques for predicting FFB quality parameters on trees. The results determined whether the FFB has ripened and ready to be harvested. The second category uses the NDE to perform grading process for FFBs after they had reached the oil palm mills for further processing. With the average milling capacity of 1000-2000 tons per day, the grading process in mills required a system that can delivered large working capacity with excellent accuracy and consistent grading results. The system should able to perform segregations of the FFB and remove substandard bunch from the processing line, to prevent it from entering the milling process, which may degrade the quality of CPO produced. The third category of NDE system performs the assessment of FFB quality in situ, before transported to the mills for processing. This group has high mobility due to its simplicity and limited number of devices used in the system. The accuracy of assessment results became the priority for this category, due to minimal number of components used in the system, to ease the mobility of the system in the plantation. All seven NDE techniques are summarized in Table 1. Each category of the NDE techniques that can be applied for quality inspection of oil palm FFB in Indonesia are discussed in the following subsections.

Table 1. NDE application for FFB quality inspection in Indonesia

Developer	Sensing Device(s)	Working capacity	Assessment accuracy	Device Mobility	Operational time	Effective Detection range	Working principal
Makky *et al*., 2004	3D stereo camera	1 FFB at once	100% (Ripeness)	Low	Limited by operator	0.3-4.5m	Stereo imaging of FFB, Harvest
Makky *et al*., 2012; Cherie *et al*., 2012, 2015a, 2015b; Makky and Soni, 2013b	Modified Camera with Long range lens	3 min / FFB	>90% (Ripeness); >85% (Oil Content); >80% (FFA)	Very High	Limited by batteries (approx. 4hr)	2-20m	Imaging selected FFB, Harvest decision
Makky *et al*., 2012; Thoriq *et al*., 2012; Makky and Soni, 2013b	UV/Vis Spectral	1 min / FFB	>95% (Ripeness, Oil Content, & FFA)	Very High	Limited by batteries (approx. 4hr)	2-15m	Imaging selected FFB, Harvest decision
Makky *et al*., 2008	Sensitive photo-selective sensors	1 ton FFB/hr.	>80 % (Ripeness)	Static	Limited by operator	0.95 m	Grading FFB
Makky and Soni, 2013a; Makky *et al*., 2014	Machine-vision	5 tons FFB/hr.	>88% (Ripeness), >85% (OC), and >80% FFA	Immobile	Non-limited	0.95m	Automatic grading, and quality prediction
Makky *et al*., 2012; Makky, 2016	Camera-vision	1 FFB/2 min.	>88% Ripeness), >80% (OC), >25% (FFA)	Portable	Limited by batteries (approx. 4hr)	0.95 m	Quality prediction
Makky and Soni, 2014	Vis/NIR Spectral	1 FFB/3 min.	>90% (Ripeness), >85% (OC), >85% (FFA)	Portable	Limited by batteries (approx. 4hr)	0.95 m	Quality prediction

The first category of NDE techniques for FFB quality inspections

There are three NDE systems for FFB quality inspection which can be grouped into this category. The three systems are the NDE technique for identification and locating ripe FFB on plants for harvest using stereo 3D machine vision; the camera vision for FFB ripeness stages determination on plants to perform harvest prediction; and the spectroscopy analysis for ripeness determination of intact FFB on plants in order to perform harvest decision.

NDE technique for identification and locating ripe FFB on plants for harvest using stereo 3D machine vision

This system was developed to utilize the stereo camera vision as its sensor. The stereo camera vision enables the system to provide color information from the FFB under consideration as well as its position on plants. This information can be used by the system to determine the ripeness of the FFB sample, and made decision for harvesting. This NDE system, which will serve as a sensing device for the FFB harvesting machine, provide cutting coordinate to the machine to cut the FFB's stalk without causing any injuries both to the plant and the FFB. The cutting position determined based on the FFB size and orientation in the images, as well as the difference of FFB center point in images recorded by the left and the right camera. The prototype has limitation, and only capable to perform harvest identification for the FFB from the distance of 4.5 meter or closer. The limitation mainly caused by the availability of camera technology when the prototype was developed. In addition, the stereo camera vision should be directed toward the FFB on plants in horizontal position, thus the system needs to place the sensor as high as that observed FFB on tree. Furthermore, due to the limitation of harvesting machine arm, which can only reach maximum vertical distance of 7 meter, this prototype can only be used for short palm tree where its FFB located less than 7 m above the ground. Moreover, the size of the harvesting machine designed limits the system movement, and required a track platform, thus prevent the system to freely maneuver in the field. Another limitation for this system is the processing time of the images, which may take up to 15 seconds to deliver the results. In addition, considerable time is required by the arm to position the camera facing the FFB correctly. Based on these limitation and drawback, the system is not ready to be operated in real condition in the field. However, since it was developed in 2002, the system considered as the pioneer of NDE application for FFB quality inspection on trees, in particular, it is the first system reported to perform FFB quality inspection on plants using 3D stereo camera vision. The limitations of the system were mostly related to the availability of technology at that time. This is the first system that able to identify ripe FFB on tree, and distinguished it from other non-ripe bunch. Moreover, the system also the first one to have the capability pointing cutting point for harvesting the ripe FFB on plant.

Camera vision for FFB ripeness determination on plants for harvest prediction

The second system in this category use camera-vision-based observation, and when combined with adequate lens, it allows the observation of FFB from 20 meters. Therefore, this system is capable to determine the quality of FFB on tree, in various plant heights. The system comprised of a portable computer, a camera, and a tripod to place the camera. The whole system weighted around six kilograms; therefore, it is light enough to be carried by an operator. The flexibility of this system enables observation of FFB on tree from different positions, well-suited for infield operation. The system has several limitations, for example to select the FFB for observation; the operator has to distinguish the bunch from other non-ripe FFB based on color differences. Another way to select the FFB for observation is by counting the detached fruitlets that fell around the tree trunk, indicating the changes in metabolic process due to physiological development when the ripening take place.

Currently, the system required the help of an operator to position the camera on the tripod and directing the camera lens toward the FFB under consideration. The operator should place the camera so the FFB can be directly seen by the camera sensor, without any obstruction. The recorded FFB images were stored in the computer, and directly processed by the image processing software for segmentation, to remove background and other non-interest objects. The remaining object in the image will be the observed FFB. The color information from object was extracted and used into FFB quality assessment model to calculate its ripeness and oil content. The whole assessment process takes places in three minutes, and has been tested directly in the field. Several drawback in the system observed, particularly when the camera directly facing the sunlight. In this case, the objects in recorded FFB image form a silhouette, and the color information cannot be extracted from the image. This condition can be circumvented by locating the camera in new position, however, some midrib that may obstruct the camera view need to be removed. Another limitation of this system is the operational time, which limited by the battery capacity in the camera and portable computer. Moreover, this system cannot be operated under wet condition.

Spectroscopy analysis for ripeness determination of intact FFB on plants in order to perform harvest decision

This system has similar working principles with number 2 system, however, the sensing device replaced by a UV/VIS spectral, which capable to analyze light reflectance with the wavelength of 280-850nm. Similarly, this system required identification to select FFB for observation, through color differences of by counting the number of detached fruitlets around the tree trunks. The operator needs to position himself in order to clearly see the FFB. The spectral then directed to the FFB, assisted by the laser pointer to pinpoint the monocular direction to the center of the FFB. The incoming light received by the probe subsequently measured by the spectral and recorded. This spectral data will be used by the model to calculate the ripeness and oil content of the FFB. Compared to the similar system with camera vision, this system has the weight and flexibility advantages, since the system did not required cumbersome lens. In addition, the system delivered more accurate predictions compared to camera-vision based systems. However, the UV/Vis spectral used in this system is very sensitive, and need to re-calibrate frequently. Moreover, the UV/Vis spectral was considerably more expensive compare to camera, thus this system it less economical to be used widely in oil palm plantation. The influenced of sunlight also caused alteration to the measurement, particularly when the light directly fell onto the probe surface. The system also has limited operational time due to the battery capacity, and cannot be operated under wet days.

The second category of NDE techniques for FFB quality inspections

In the second category there are two developed NDE systems for assessing the FFB quality by means of grading using photo-selective sensors and camera vision. These systems performed segregation of substandard FFB from the processing line, and can delivered substantial work capacity, to fulfill the grading requirements in the mills. Even though these two systems work similarly, the differences sensing device and mechanism influence the prediction rates of these machines. The two systems mentioned are the FFB grading machine using photo-selective sensors; and automatic grading machine for oil Palm FFB based on camera vision.

FFB grading machine using photo-selective sensors

This NDE system worked by evaluating reflected lights from FFB surface at the time it passed the sensors. The sensors were photo-selective lights transistors, arranged crosswise in a single row above the conveyor belt, facing down perpendicularly to the conveyor. The light sources were LED lights array, arranged parallel to the sensors. The lights illuminated the surface of FFB passing below the sensors and lights. The FFBs were load manually onto the conveyor, and the segregation performed by closing the sorting gate in order to prevent substandard FFBs enters the processing line. The prototype of this system had been successfully developed and tested in 2008, although the tests were carried out indoor. The system has several limitations, such as the lack of enclosed inspection space, lead to fault assessments results, caused by interference of sunlight to the sensors surfaces. Another problem occurred during testing the prototype, caused by the material used for the conveyor. The selection of fabrics as the conveyor belt material caused the spikelet of the FFB frequently stuck into the fabrics, and hampers the segregation by the sorting gate. Nonetheless, the system has good accuracy when operated in a closed room, and not directly exposed to the sunlight. This system was able to correctly segregate substandard FFB for more than 80%. However, when tested with FFB from nigrescence cultivar, the system cannot perform segregation properly, due to the color resemblance between the ripe and unripe FFB.

Automatic grading machine for oil Palm FFB based on camera vision

In this system, the grading process as well as segregation was done automatically. However, the FFB samples still loaded manually onto the conveyor belt, which transport the bunch into the inspection chamber. The FFB quality assessment as well as the segregation in this system delivered high accuracy and consistency. Compared to the first grading machine, which uses photo-selective sensors, this grading system delivered better performances, and accurately identify and segregated substandard FFB, including the nigrescence cultivar. The digital camera used as the main sensors in this system, obtained more complete color information from the recorded FFB images. Therefore, the quality prediction model, developed for this system, could be made more complex, for example by employing multilayer-perceptron neural network algorithm. Thus, the model can predict quality parameters of the FFB accurately. Equipped with the inspections chamber, this grading system can be used outdoors, where the assessments can be performed with no influence from the sunlight. In addition, the design, material and type of the conveyor used in this system were also enhanced, based on the experience upon developing the first grading machine. Therefore, the grading process in this system can be seamlessly performed in shorter time. The machine can perform FFB grading with the capacity of 5 tons / hour. This system is currently under further development, in order to be accepted and integrated into the processing line at oil palm mills in Indonesia.

The third category of NDE techniques for FFB quality inspections

The NDE systems in this category estimated the quality parameters of the FFB on trees. There are two developed systems in this category, namely the low-cost portable inspection system for oil palm FFB using camera-vision, and the rapid portable inspection system for oil palm FFB using Vis/NIR Spectroscopy. Both systems have similar working principle, although the sampling methods and information obtained from the FFB samples were different. The sensors used in both systems have their own advantages, such as assessment speed, processing time, mobility, and cost of the system. Nonetheless, the operator skills remain the primary factor for inspection accuracy. These systems developed to reduce the costs of transporting substandard FFBs from plantations to the mills.

Low-cost portable inspection system for oil palm FFB using camera-vision

This FFB quality inspection system can be used in situ where the assessment performed using the camera vision technology. This portable inspection system recorded the FFB images inside an inspection chamber and extracts all color features from the images by means of image processing to be used for predicting the FFB quality. In practice, the inspection takes place by bringing the system to the FFB collecting stations in the plantations area. Before these FFBs loaded into the truck and transported to the mills, each FFB quality will be inspected by this system. Substandard FFB will be separated and will not be load into the vehicle. This will reduced the transportation costs in the corresponding company. The system has independent power supply, and did not require power sources, which may not available in the field. In addition, the high mobility of the system allows inspection to be carried out at other locations; therefore, one system can be used for FFB quality assessment in different collecting sites. Some limitations observed in the system. The operating time is limited by the battery capacity in the system. The system may works for several hours, before the batteries need to recharge. The time required by the system to process the recorded images and calculated the results specify the whole inspection period. The portable computer used in this system could performed 92 billion Instructions per second at 2.93 GHz (Tom's Hardware, 2011), therefore, the lag of the image processing time probably related to the architecture of the software used or the programming language used to develop the software. Furthermore, since the image processing program still used the native core set of application programming interfaces (APIs), provided by the operating systems, the program should incorporated these features upon processing the image, thus increased overall analysis time. In addition, the procedure of FFB quality inspection in this system, where the samples should be placed inside the chamber, increased the overall examination time. In general, the developed system has successfully been tested in the field, and received acknowledgement from the oil palm company, where the tests take placed.

Rapid portable inspection system for oil palm FFB using Vis/NIR spectroscopy

The second NDE system in this category examines the FFB quality using Vis/NIR spectral by measuring the light reflected by the FFB surface. This system did not required to recorded the whole FFB surface, instead, only three measurements were performed at different points on FFB surface, the sampling were done at three location along the FFB equator, separated by 120o between each measurement point. The reflected light from the FFB surface measure by the spectral are the lights with wavelengths of 380-1100nm. In contrast to first portable system, the inspection in this system carried out directly, without requirement to place the FFB inside the inspection chamber, therefore, the assessment can be done faster. In addition, the spectral data from the sampling can be directly feed into the model for calculating the FFB quality features. The spectral data consist of 2000 light reflection information; provide more significant information to the models, thus the predication results for the FFB quality parameters are more accurate compared to the first portable system. Nonetheless, this system also has several disadvantages, such as the spectral need to recalibrate frequently after several measurements. In addition, the halogen lamp in the spectral is needed to be replaced after being used for 400 hours. Added with the initial costs of the Vis/NIR spectral system, which may reached five times the price of the camera, makes this system less economical, when compared to the similar portable inspection system using the camera. Nevertheless, this system opens the opportunities for more simplified designs, for example by using multiple wavelengths of lights that have the most significant correlation with the quality parameters of the FFB. (Saeed *et al*., 2012).

Conclusion

This paper outlined several applications of the NDE system that used for assessing the FFB quality parameters in Indonesia. The developed systems could predict three quality parameters of the FFB, namely ripeness, oil content, and FFA levels. In general, all NDE systems discussed in this paper utilized photo-sensitive sensors, camera-visions, or spectroscopy analyses to perform quality inspection for oil Palm FFB. Based on their applications, these NDE inspection systems for oil palm FFB can be grouped into three categories. The first category is the systems for evaluating the FFB quality parameters on plants. The evaluation results will determine harvest decision for the corresponding FFB. The second category systems were used for grading the FFB in mills. The grading processes evaluate the quality of incoming FFB in the in-line processing, and segregate substandard FFB from the processing line. The inspection systems in this category were characterized by its large working capacity and the use of conveyor belt. In the third category, the developed systems perform quality assessment before the FFB transported in to the milling sites. The objective of NDE systems in this category was to reduce the transportation costs and increased the overall transportation system efficiency. In addition, these NDE systems prevent the transportation of low-quality FFB to the processing Mills. The whole NDE based FFB quality inspection systems that have been developed in Indonesia have several advantages and limitations, and there is still room for improvement. The advantages are among other improving the efficiency of overall harvest and reduce loss in mills by preventing entrainment of substandard bunch into the processing line. From this review, the development and application of NDE systems in Indonesia, especially for FFBs quality inspection, did not fall behind the other oil palm producing countries

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