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# Towards Sustainable Green Production: Exploring Automated Grading for Oil Palm Fresh Fruit Bunches (FFB) Using Machine Vision and Spectral Analysis

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***Abstract*— Over the last decade, Indonesian palm oil industry has become a leading producer of the world, and been able to generate notable foreign export reserves. In spite of this, problems still persist in this industry, including low productivity due to mishandling of raw material in post-harvest operations. One of the prime causes of this is manual grading/sorting of fresh fruit bunches, which is prone to error and misjudgement, as well as subjectivity. High demand of oil palm establishes its high price in world market, which drives the industry to expand its plantation area to increase production. Ultimately, it compromise forests and agricultural land, resulting stagnation or decline in several food products. Alternatively, before expanding plantation extent, oil extraction productivity of existing plantation can be improved by carefully selecting appropriate FFBs for post-harvest processing through introduction of automation. The use of machine vision and spectral analysis has shown to assist productivity of agricultural processing industry. This study employs automation technology for FFB grading in oil palm mills, resulting in improved raw material quality, thereby increasing the oil extraction productivity, and simultaneously contributing to partly release the pressure of deforestation by maintaining green agricultural areas.**

***Keywords*— Oil Palm FFB; Automation; Grading; Machine Vision; Spectral Analysis**

## I. Introduction

Oil palm industry plays a major role in Indonesian economy and supplies 45% of world's consumption [1]. Although suffered from various problems, such as heavy taxation from importer countries and occasional sanctions from the European Union and the United States due to environmental and oil palm industry standards related issues, yet the industry remains as strategic importance to Indonesia [2]. The oil palm is edible oil extracted from mesocarp of fruits of oil palm trees (Elaeis guineensis Jacq.). The fruits forms large bunch known as fresh fruits bunch (FFB). The quality of FFB itself can be determined by its condition *e.g.* ripeness, damage or bruises [3]. The ripeness of FFB is observable through its colour [4].

Over the last three decades, oil palm plantations in Indonesia have growth from a merely thousands of Hectare (Ha) in late 1988 on to more than 9 million Ha [5] in 2012 (Fig. 1).The rapid expansion is made possible through conversion of forest and other agricultural land. However, due to environmental concern as well as implementation of regulation that restrict further land expansion for this industry, a new challenge emerge on how to increase oil production (CPO) with currently available land.

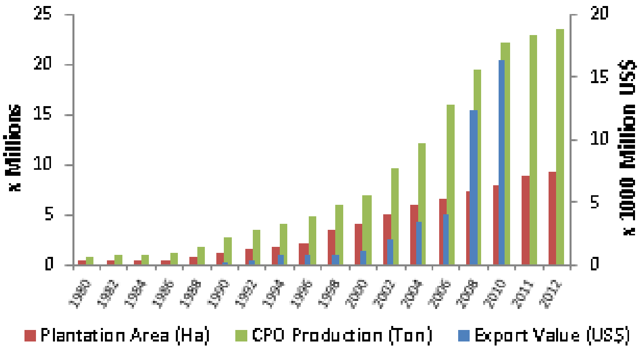


Fig. 1 Indonesian oil palm plantation areas, productions and exports [5]

This paper attempt to introduce recent engineering solutions to be implemented by the oil palm industry which allow addition of production and revenue using available developed technology, while reduce dependency of land expansion.

## II. MATERIALS AND METHODS

### *A. Sites Location*

The study was carried out in Lebak area (6°18' - 7°00' S and 105°25'-106°30' E), Banten province, and Cimulang area (6°30'-6°32' S and 106°41'-106°45' E), West Java province, Indonesia (Fig. 2)

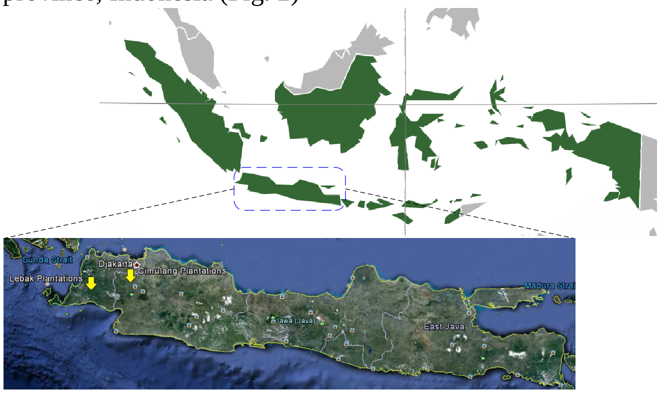


Fig. 2 Study sites and oil palm plantations location in Java island, Indonesia (yellow arrows)

Banten and West Java province located in the western part of Java Island (105°05'-108°50' E, 5°55'-7°50' S). The province has tropical monsoon climate, suitable for oil palm plantations. In Indonesia, among others, Java is the second island introduced to oil palm plantation and the area are growth ever since.

The selection of this area is based on the unique situation, where high population density (1000 people.km$^{-2}$), presence competition between residential, farms and forests, greatly hindered expansion of oil palm plantation area. With the limitation of planting area, the source of raw material (FFB) to be processed in this area is limited. This conditions demand improvements for processing efficiency, so it can retrieve more product (CPO) with better quality, using similar number of inputs and raw materials (FFB).

### *B. Selection of Technologies to be Introduced*

One way to improve the production is to revise the method of raw materials selection to be processed in mills. In this stage, selection is done through human visual inspection, where expertise and experience affect the accuracy of the results. In addition to time-consuming, this process tends to heavily bias due to subjectivity and other factors. Ultimately, the amount and quality of oil palm oil produced is much less than optimum conditions, resulting from processing low quality raw material. Many FFBs fed into oil processing cycle do not comply with the standard provisions of the mills.

One of parameters used to select good FFB for the CPO processing is the maturity of the fruits. With the ripening progress, chemical and biological reactions occur in the fruit, and cause transformation of pigments in the fruit's skin, so that the colour of the bunch is changing. Therefore, the fruits ripeness can be observed through the bunch's colour. In addition, changes of fruits colour also showed an evolution in the chemical content of the fruit, which correlated to oil content in the fruit. Thus, by accurately observed the fruits colour the ripeness and oil content of the bunch can be more precisely determined, allowing the selection process performed with much better results.

Spectroscopy and Machine-Vision are two available technologies that widely used for determining the crops quality by assessing its colour. These technologies allow analyses of both the internal and external properties of the crops without damaging the object.

### *C. Application of selected technology to be used for grading FFB as raw materials for oil palm mills*

Even though there are many studies to understand how to determine the ripeness and chemical content of oil palm FFB by means of optical approach, yet, practical design or prototype that can be implemented in the palm oil industry is not available until now, especially in Indonesia. Several studies have been carried out to assess oil palm FFB properties using optical devices, such as camera [6],[7],[8], Color meter [9], as well as visible and non-visible spectrum [10],[11]. However, it was found that several factors reduces the practicality and efficiency of the equipment used [12] [13].

By the end of 2011, a grading machine for FFB that can be used in-field operation is developed [1]. As the machine successively passes the entire rigorous test satisfactorily, it becomes the only choice available to be tested and compared its performance with manual grading performed by the labours in oil palm mills. Tests will be commenced in terms of work capacity comparison, between FFB graded by the machine and manually graded FFB. Tests will also be done in term of economic point, by comparing operational costs of the machine for performing grading, and number of FFB to be graded for achieving break-even point (BEP),as well as payback period of the machine.

The working capacity ($W_c$) of the machine is calculated by:

$$W_c = \frac{m_{FFB}.n_{FFB}.v_{con}}{l_{con}} x36 \quad (1)$$

Where $W_c$ is the working capacity of the machine(kg/h); $m_{FFB}$ is mass of FFB samples (kg); $v_{con}$ is the linear speed of the conveyor belt(m/s); and $l_{con}$ is the length of the conveyor(m).

The introduced machine is capable of classified FFB according to its appearance, and ripeness fractions, while being able to determine the sample weight. The accuracy of the machine to determine the FFB is regarded as the degree of closeness of measurements of FFB properties to its actual (true) value. The parameters were calculated using equation:

$$R^2{}_{(i,j,k)} = \frac{t_r + t_o}{n} x100 \quad (2)$$

Where$R^2$ are the machine classification accuracy (%) of FFB class (i), fraction (j), and weight (k); $t_r$ is the total classification correct; $t_o$ is total classification incorrect; and n is the total samples of FFB.

The economic analysis of the machine is performed to determine the operational cost, breakeven point (BEP) as well as payback period of the machine. The calculation was based on cost analysis suggested by [14].

The Operational Costs of the machine consists of fixed and variable costs. Fixed cost is calculated hourly using the equation:

$$F_{c_H} = \frac{\left[\frac{(P^2-2PS+S^2)(N+}{2N^2+SN}\right.}{H} \quad (3)$$

Where $F_{c_H}$ is the hourly fixed cost of the machine ($/h); H is the working hour of the machine (h); P is the initial investment of the machine ($); S is the salvage value of the machine ($); and N is the machine economic life-time (yr)

The machine's variable cost per hour ($V_{c_H}$) is determined by the following equation:

$$V_{c_H} = E_H L_H \quad (4)$$

Where $V_{c_H}$ is variable cost of the machine per hour ($/h); $E_H$ is the cost of electricity or fuel per hour to run the machine($/h); $L_H$ is the costs of labour per hour($/h); and $R_H$ is maintenance cost per hour($/h).

Given the hourly fixed and variable costs, the operational cost for the machine to perform grading ($G_C$) can be calculated as:

$$G_c = \frac{F_{c_H}+}{W_r} \quad (5)$$

Where $G_c$ is the actual grading cost of FFB($/kg).

The BEP is expressed as the number of FFB graded per unit of time in order to cover the fixed cost of the machine. BEP is simply computed as the point where contribution equals to total fixed cost. BEP is calculated as:

$$BEP = \frac{\left[\frac{(P^2-2PS+S^2)(N}{2N^2+SN}\right.}{B_P - V} \quad (6)$$

Where BEP is the breakeven point of the machine (unit/year); $B_P$ is the unit sale price ($); and V is the unit variable price ($).

The payback period of the machine refers to the period of earliest time required to repay of total investment. It can be calculated as:

$$T = \quad (7)$$

Where T is the time of payback (yr); ΣI is the sum of investment made for the machine; and Rev is the annual revenue for using the machine.

## III. Results and Discussions

The developed prototype (Fig. 3) comprised of several peripherals and components that automatically run upon assessing the bunch. The machine vision section comprised of a camera, the inspection chamber, a computer, and a image processing program to capture the FFB image, and segmented it before extracting the features to be used for determining the bunch properties.

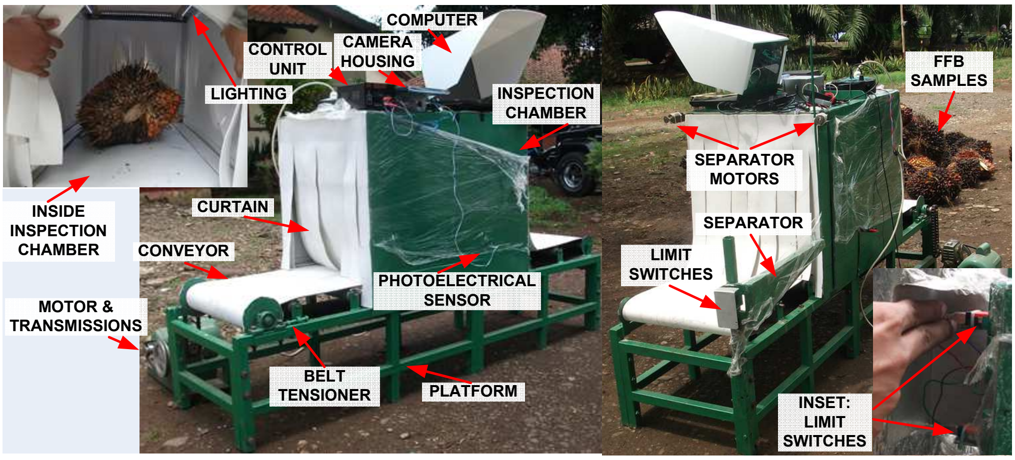

Fig. 3 Peripherals and components of automatic grading machines for oil palm FFB

The working capacity of the prototype is estimated as high as 8850 kg/h. However, upon performance test, the actual work capacity of the machine in averaged only achieved 6135.8 kg/h. Several factors influenced the test results, one of which is the procedure of loading the samples material onto the machine that still performed manually by the labor. Although this practice hindered the machine to achieved optimum working capacity, it is a necessity to reduce the complexity of the machine, while on the other hand it still providing employment for the labor. Another factor why labor is still required to operate this machine is, it might reduce the reluctance or refusal upon application this machine in the oil palm mills. A fully automatic machine is still being considered as threat to employment, especially in remote areas where oil palm plantations are cultivated

As for the accuracy of the machine to assess the FFB properties, the inspected FFB are successfully grouped into two class (Fig. 4) with $R^2$ of 94.1%, and standard error prediction (SEP) of 0.5605.The first class (Class 1) represents as low quality FFB and considered to be removed, while the second class (Class 2) is considered as good quality FFB and therefore it fit to be processed into oil palm by the mills.

Asides of being able to determine the quality of inspected FFB, the prototype can also gave the ripeness level for each FFB, along with its weight. This become another advantage of the machine, and enable the processing to be more accurately determined how much total raw material (FFB) processed, how much the input (kg) material in the processing line, as well as the composition of the raw materials (FFB ripeness). With this information, the estimation of product outcome (CPO) that will be obtained along with its quality (FFA level) can be performed more accurately, and gave a hint to the mill on how much revenue they can made. Another advantage is the requirement of chemical material needed for producing the CPO can also be estimated more precisely, and therefore might increase the production efficiency while in the same time reduced the production cost.

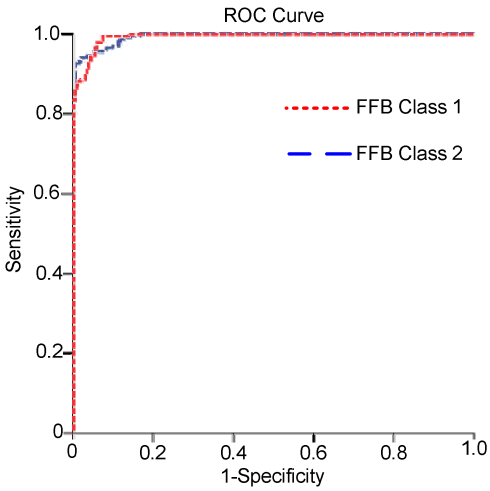


Fig. 4ROC curve of FFB model for class prediction

The operating cost to operate the grading machine consists of fixed and variable costs. The fixed operating cost is the product of annual depreciation value of machine and annual bank interest, while the variable costs are the input requirement to enable the machine run properly. The initial investment of the machine is considered as \$ 5000. This value is the minimum amount of money required to develop the prototype. With the assumption that the cost of material and equipment for industrial-scale production will not exceed the cost of the prototype, the purchasing price of the machine is therefore considered similar to \$ 5000.

As the annual depreciation value of the machine calculated as\$ 990/yr., and annual bank interest rate obtained as\$ 145.2/yr., the fixed cost for the machine operation per hour is calculated as 0.24 \$/h. This value is obtained after taking the consideration of operational hour in the palm mills, which commonly work 18 hours in a day within 22 day for a month, and average machine capacity of 6135.8 kg/h.

Since the operation of the machine required a labor to load the FFB manually, the labor cost is included in variable costs. However, the cost for electricity to run the machine is not included in the variable costs, since oil palm mills generate their own electricity with abundant in excess. Standard labor cost in Indonesia is 1.3 \$ per hour per person [15]. As for the maintenance cost, the value is calculated as 0.1 \$/hr. given these data, the operational cost for the grading machine can be calculated as \$ 0.00027/kg. The current purchasing price of FFB is 0.16 \$/kg, and therefore, operation cost of machine is considered as low (± 0.17%). In comparison, manual grading required three labors to inspect a 5 to 7 ton FFBs within 2 hours, with annual costs of 8336.8 \$ or approximately 0.5 – 0.7 \$/kg.

Machine BEP is calculated in order to understand how the machine beneficially compared to manual grading. The break-even point for the grading machine simply computed as 4,204,444.4 kg/yr. With this number, the payback period of the machine is obtained as 40 days operation. Therefore, from the 41$^{st}$ day onward, the operation of the machine will give benefit to the palm mills.

In addition to lower operation costs and minor initial investment, the applications of the machine can be beneficial to quality improvement of processed FFB, thus providing a better products output, in term of quantity and quality. Compare to manual FFB grading, the use of grading machine potentially encourage stricter harvesting routines and processing with minimum delay. With this practice, a Stabilized Prime Bleachable CPO (SPB CPO) with FFA levels in CPO less than 2% can be produced. It is outstanding quality oil compared to current CPO quality with 5% FFA. With the implementation of the machines in oil palm mills, and coupled with improvement in managerial sector, it is feasible to achieve SPB CPO product widely in Indonesia, using similar or even lower production cost, compared to current manual operation.

If this goal can be achieved, not only the number of CPO production can be increased nationally, but also the quality of CPO produced will become greatly enhanced, thus providing far greater benefits for the oil palm industry and for the country, through taxes revenue lifting. On the same time, the implementation of this machine will reduce the negative effects of the enforcement of regulation by the government of Indonesia that restricts plantation area of oil palm industries. The industry will no longer focus on land expansion for plantations area to increase their production, but differ their efforts to another options of technology application to improve the efficiency and quality of their products. This in term will indirectly reduce the rate of deforestation and conversion of food agricultural land in Indonesia. Ultimately, it will impact the viability of agricultural and industrial production to become greener and friendly to the environment.

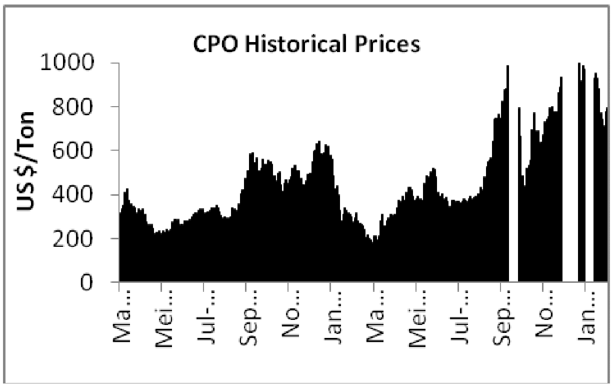


Fig. 5 Monthly historical CPO prices (1988 – 2013) [16]

Over the years, CPO from Indonesia constantly imposed discount price by importer, as much as 500 rupiah per kilogram [17] (approx. 5 cents \$/kg), due to its low quality. With the annual CPO production of more than 23 million tons in 2012, oil palm industry in Indonesia suffered 1.27 billion US dollar loss annually, equivalent to 7% of its annual revenue from CPO export.

The utilization of FFB grading machine by oil palm mills bring the opportunity to minimize this loss, by producing much better palm oil quality, in which the input of the process (FFB) can be segregated restrictively. The potential loss by oil palm industry each year can be referred as loss of exported CPO as much as 1.6 million tons per year, or equivalent to the waste of yield from 411 thousand hectares oil palm plantation (Fig. 6).

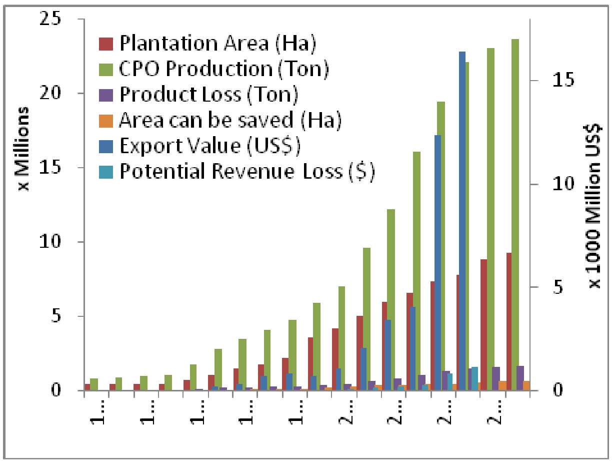


Fig. 6 Effect of discount price imposition to Indonesian oil palm industry

Overall, the introduction of automation technology to control the quality of fresh fruits bunch used in the oil palm processing plant will produce a better quality output and promote reduction in loss due to imposition of discount price by CPO importer. This in turn might save the yield output from more than 400 thousand hectares of oil palm plantation annually. In all, the increase of production efficiency can be obtained by the Indonesian oil palm industry while in the same time maintain the sustainability of the industry itself.

## IV. CONCLUSION

In conclusion, the introduction of recent engineering solutions, in this case is automatic FFB grading machine for oil palm processing plants, can be implemented by the oil palm industry in Indonesia to allow them achieved additional revenue using the developed technology, while in the same time reduce dependency of land expansion and promote sustainable and greener oil palm productions.


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