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LINEAR OPTIMAL CONTROL MODEL FOR FELLING THE OIL PALM TREES

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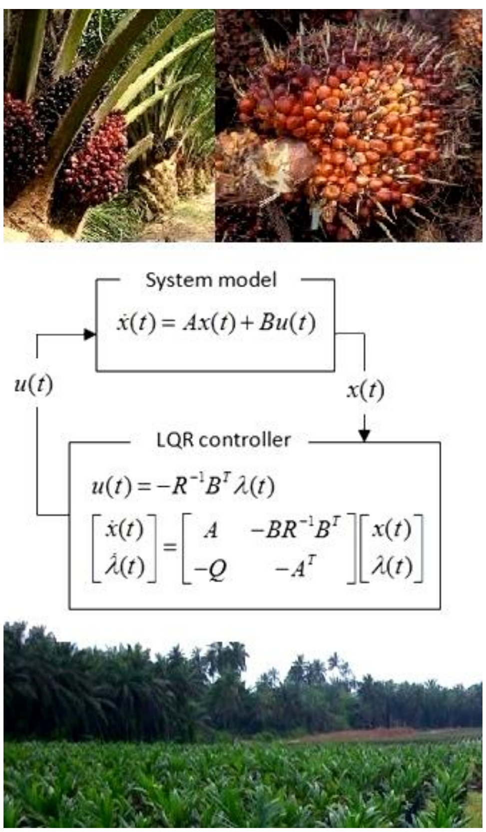
Graphical abstract



Abstract

The increases of operational felling cost have prompted the oil palm industry to look at the current practices. The felling activity is considered as the main aspects to improve and maintain palm oil production through the provision of effective and agronomic practices. To support this success and achieve minimum cost of operation, this study aims to develop a time-invariant linear quadratic optimal control model for controlling the felling and harvest rate of the oil palm plantation. The proposed model involves two state variables which are biomass and crude oil. The optimal parameters for the model are estimated using a set of real data collected from Malaysian Palm Oil Board (MPOB). The study analyzes the solution of the resulting control problem within a limited time frame of 30 years and the results provide an optimal feedback control for the felling and harvest rates.

Keywords: Linear Quadratic Regulator (LQR), Optimal Control, Palm Oil, Felling, Mathematical Model

Abstrak

Kenaikan kos operasi penebangan pokok kelapa sawit telah mendorong industri ini untuk menilai amalan semasa. Aktiviti penebangan dianggap sebagai aspek utama untuk meningkatkan dan mengekalkan pengeluaran minyak sawit melalui penyediaan amalan yang berkesan dan agronomi. Untuk menyokong kejayaan dan mencapai kos minimum operasi, kajian ini bertujuan membangunkan model kuadratik optimum kawalan linear masa tak berubah bagi mengawal kadar penebangan dan tuaian ladang kelapa sawit. Model yang dicadangkan melibatkan dua pemboleh ubah keadaan, biomas dan minyak mentah. Parameter optimum model ditentukan daripada set data yang dikumpul dari Lembaga Minyak Sawit Malaysia (MPOB). Kajian ini menganalisis penyelesaian masalah kawalan yang terhasil dalam tempoh masa yang terhad selama 30 tahun. Hasil keputusan menunjukkan kawalan maklum balas optimum untuk penebangan dan kadar tuaian.

Kata kunci: Linear Quadratic Regulator (LQR), Kawalan Optimal, Minyak Kelapa Sawit, Penebangan, Model Matematik

1.0 INTRODUCTION

The Malaysian oil palm plantation has grown in size and become one of the world's leading producers and exporter in palm oil industry. Planted area at the end of 2015 has reached to 5.3 million hectares increased about 7% from 2011 planted area. Nevertheless, within these years, crude palm oil yield showed decreasing values from 4.01 to 3.84 tonnes per hectare whereas cost of operational and maintenance and palm oil prices continue to increase [1]. Despite fluctuating prices depicted in Figure 1 and high operational cost shown in Table 1, the palm oil has high returned profitability that attracts a huge number of small planters and large organization to venture into this plantation.

Furthermore, the positive growths under Malaysian tropical climate and equally distributed rainfall have made this plantation successful. However, the uncontrolled and inefficient activities of harvest and felling of oil palm tree affect the revenues, increase the cost of operations and maintenance while reduces productivity [2].

Generally, the crude palm oil is produced continuously but the productivity is reduced after 25 years and declines more rapidly until the trees no longer bear fruits. At the same time, trees that grown too high are difficult to harvest. Therefore, after 25 years, the palm tree is no longer has commercial value, thus palm tree should be fell down for replanting. The concern is, how long it takes to felling unproductive trees and how to control the felling rate such that the cost of operation and maintenance is minimized.

A mathematical model for oil palm plantation is required in order to study the system and to secure its profitability. However, it is rare indeed to find optimal control formulation model for felling oil palm plantation problem. In addition, it is hard to make use of other mathematical models that are suggested for different biological systems [3], [4]. As a consequence, the aim of this paper is to establish a system of ordinary differential equations that take into account controlling the optimal felling rate of oil palm trees.

Table 1 Felling and planting cost per hectare

Cost of Field operation (MYR Per hectare)		Source
Felling & Clearing	Planting	
1,422	357	[5]
1160	296	[1]
962	222	[1]
606	Not Available	[6]

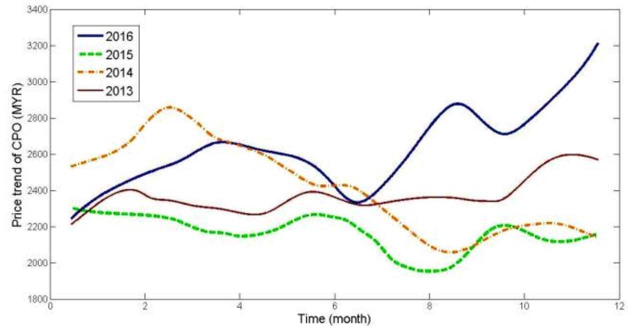


Figure 1 Crude palm oil prices trends from 2013 to 2016, *collected from:* Malaysian Palm Oil Board

The rest of this paper is organized as follows. In the next section, the related works are introduced. The third section presents the model of the system and the approach to estimate the optimal parameters for the model. The solution procedure of the resulting control problem is discussed in the fourth section. Following that, the results are illustrated and finally in the last section, some concluding remarks are presented.

Harvesting is a process of removing the ripe bunches to extract the Crude Palm Oil (CPO) yields [7], while felling activity is a process of eradicate the whole tree from the ground. Harvesting literature is popular among researchers and a harvesting problem is considered the most natural and important variables to describe population dynamics for many kinds of species [8]. While leaving the old oil palm tree without felling is a problem that most researcher and planters less considered, even though the fact that felling tree can be recycled to organic matter [9].

The CPO productivity is determined by the ripeness of the fresh fruit bunches (FFB) [10]. However, the FFB productivity and CPO yields are reported to be affected by the management criteria such as land preparation, harvesting, planting, technical management and environment [2], [11]. Despite above attention, less study is conducted on the important of controlling the felling stage.

The time of harvesting is normally subject to various ripeness condition such as the colour of the fruit surface, staining method, laboratory testing, size of fruit and age of trees [7], [10]–[12]. Planters and researchers assumed that the harvest will take place twice a month [7], [13]. There are times of harvesting not allowing to be carried out which are during herbicide spraying, pesticide application or fertilizer application, floods and excessive water [14]. Other than these times, it is possible for harvests activity to be carried out throughout the year provided that the fruit ripeness. Yet times of felling the trees are less considered by the planters.

Normally, trees are fell when they are 20 to 30 years old [9], [10], [15], [16]. In 2008, Wahab *et al*. [15] reported that the felling or removing the oil palm tree from the ground is based on the criteria of age, tree that less produces of FFB, and tree with no longer economic value. The time range, however, can be considered as a long time for felling and clearing activities, that automatically increase more cost and time. Thus, in order to have continuous harvesting, felling should be considered as highly important as harvesting. Otherwise, uncontrolled activity of felling could increase the lifespan of unproductive palm tree, increase the operational and maintenance cost to the management and reduce continuous profit.

Ismail and Mamat [6] have studied the replanting age of oil palm tree that depends on the price, cost, technology and discount rate of FFB. They found that the optimal result for replanting age should lies between 24 to 25 years if the price of FBB increases, or the higher the expected future price the shorter the optimal replanting age. This research is done by comparing the marginal net revenue. However, they provided lesser attention on felling tree and they did not present any mathematical formulation model for replanting the oil palm tree.

Cost of felling is approximately 3 times more higher compared with any land preparation including replanting (see Table 1). Furthermore, it is reported by Harun *et al*. [10] and supported by Sharma [14], the frequency and efficiency of harvest and felling are the major factor that contributes to the profit. Recently, a mathematical model has also presented in [17] considering two state variables namely, the density of the young palm oil trees and the part of biomass that can produce oil.

Previous papers often discussed and emphasized on the optimal replanting [6], [17] determination of the correct time for harvesting [12], yet far less research is conducted on the theoretical model of felling the oil palm tree. This statement is supported by Khamiz *et al*. [13], which points out that a lesser amount of theoretical model is formulated in oil palm industry application. Different management policies are also reported as one of the main issue in oil palm plantation [10]. Thus, to improve the management characteristics, it is important to dig and develop an optimal control model that can be used as a tool in controlling the felling rate of this plantation. As the linear quadratic model study has not been explored in oil palm industry, this study can be conducted to model the oil palm frequency and rotation rate of felling using linear quadratic regulator (LQR) model. The theory of LQR concerns with operating a dynamical system. This model provides the optimal control of felling that drives the system from the initial state to a desired final state within the minimum cost function.

2.0 METHODOLOGY

The equations of the system are defined by,

$$\frac{dx_1(t)}{dt} = \xi_1 x_1(t) - \xi_2 u_1(t) \qquad (1)$$

$$\frac{dx_2(t)}{dt} = \xi_3 x_1(t) - \xi_4 u_2(t). \qquad (2)$$

The system is controlled in order to minimize the following quadratic performance index,

$$J = X^T(t_f)SX(t_f) + \frac{1}{2}\int_{t_0}^{t_f} X^T(t)QX(t) + U^T(t)RU(t)dt \qquad (3)$$

where $X^T(t) = [x_1(t), x_2(t)]$, $U^T(t) = [u_1(t), u_2(t)]$, S, Q and R are symmetric weighting matrices which are positive semi-definite and positive definite respectively, $x_1(t)$ represents oil palm biomass, $x_2(t)$ represents the oil, $u_1(t)$ represents felling rate, $u_2(t)$ represents harvest tree. The function (3) minimizes the cost of handling oil palm plantation where the harvest and felling of tree is controlled by Equation (1) and Equation (2). The Equation (1) describes the dynamics of tree biomass after considering mortality minus the felling tree, while Equation (2) describes the oil of the oil palm plantation. Matrix Q and R are set to identity matrix, while the initial state $X(t_0)$ is also given.

The parameters from previous studies are mortality and felling rate per hectare per year, biological growth and harvest rate per hectare per year (see Table 2), while the parameter used in the proposed model is estimated based on real data collected from Malaysian Palm Oil Board (MPOB), see Table 3.

Table 2 Parameters used in the previous studies

Explanation	Value	Source
Mortality rate of oil palm tree	0.01	[18]
Felling rate	0.04	[16]
Population Growth rate	0.09	[1]
Harvest rate	3.70	[7]

In the parameter estimation procedure, the following squared error cost function was considered,

$$\sum_{k=1}^{n}(x_1(t_k) - x_1^*(t_k))^2 + (x_2(t_k) - x_2^*(t_k))^2 \qquad (4)$$

where n is the number of samples, x_1^* and x_2^* indicate the biomass and oil data respectively. The minimum of cost function (4), subject to Equations (1), (2) and given initial state $X(t_0)$ results in optimal parameters for the model. In this optimization problem ξ_1, ξ_2, ξ_3 and ξ_4 are limited on some suitable intervals around the corresponding values that are listed in Table 2. There are a few methods available to address this problem. The algorithmic procedures of these methods have already been documented and discussed in detail [19]-[23]. Therefore they are not repeated here again. The result of simulations is listed in Table 3.

Table 3 Parameters estimated using real data

Parameter	Explanation	Value
ξ_1	Natural increase rate of oil palm biomass	0.03
ξ_2	Influence on felling rate	0.018
ξ_3	Crude palm oil production rate	0.001
ξ_4	Influence on harvest rate	0.16

Please note that, planted tree is not considered in this model as the focus is to find the optimal control of felling rate and the oil palm is meant to be CPO only. It is also assumed that, oil palm trees have the same age within a hectare area and the harvesting rate is dependent on time. Although, for real application extra considerations may be needed, to scope the main objective, the effects of the weather and the chemical applications are not being considered in this paper.

The proposed model can compactly be described as below,

$$\dot{X}(t) = AX(t) + BU(t) \tag{5}$$

where the system matrix A and the control influence matrix B can intuitively be constructed considering Equations (1) and (2). The linear system (5) together with the quadratic performance index (3) forms a LQR problem. The optimal control drives the system from the initial state to a final state that minimizes the performance index. The feedback control law that minimizes the cost function (3) can be developed through Pontryagin minimum principle [24]. Following this approach a stationary condition and another co-state equation are introduced as below,

$$RU(t) + B^T\lambda(t) = 0 \tag{6}$$

$$-\dot{\lambda}(t) = A^T\lambda + QX \tag{7}$$

where $\lambda(t_f) = SX(t_f)$ is also known. The Equations (5), (6) and (7), result in the following two point boundary value problem,

$$\begin{bmatrix} \dot{X}(t) \\ \dot{\lambda}(t) \end{bmatrix} = \begin{bmatrix} A & -BR^{-1}B^T \\ -Q & -A^T \end{bmatrix} \begin{bmatrix} X(t) \\ \lambda(t) \end{bmatrix} \tag{8}$$

One approach to solve this problem is through assuming $\lambda(t) = P(t)X(t)$ for $t \in [t_0 \quad t_f]$. This results in the following Riccati differential equation,

$$\dot{P}(t) = -P(t)BR^{-1}B^TP(t) + A^TP(t) + P(t)A - Q \tag{9}$$

$$P(t_f) = S \tag{10}$$

This equation can be solved backward in time for $P(t)$. Finally, this gives the optimal control law by,

$$U(t) = -R^{-1}B^TP(t)X(t) \tag{11}$$

The above procedures illustrate a simple algorithm to solve the proposed model. At the first step, considering the final solution (10), Equation (9) is integrated. Then, in the next step, using Equation (11), the original system is solved [25].

3.0 RESULTS AND DISCUSSION

The algorithmic instruction that is described in the previous section is both simple to implement and fast to compute. The computations and simulations in this study were carried out in MATLAB. The matrixes S, Q and R are set at identity matrix. The trajectories of the control and the response of the system to this control are illustrated in the following figures.

Figure 2 shows the optimal rate of felling trees. The curve in dash line represents the optimal harvest rate while the straight line shows the felling rate. From the observation that should be no activity of felling from 0 to 15 years, according to this figure the suitable time for felling may start as early as 15 years and ended at 30 years. Figure 3 illustrates the response of the system to this control design where the curves of the biomass and oil yield are calculated in tonne per hectare. The result implies after 20 to 30 years, trees are getting. This agrees with the conventional practice that the palm trees should be cleared at the end of 25 years.

As mentioned in previous literatures, felling of oil palm trees take quite a long time, before replanting took place that may also increase the operational cost. Considering the results of Figure 2 and 3, the felling activity may be taken care less than 5 years.

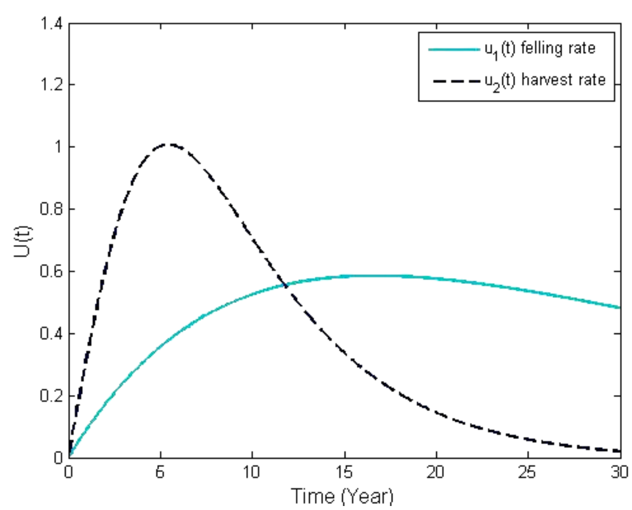


Figure 2 The optimal control

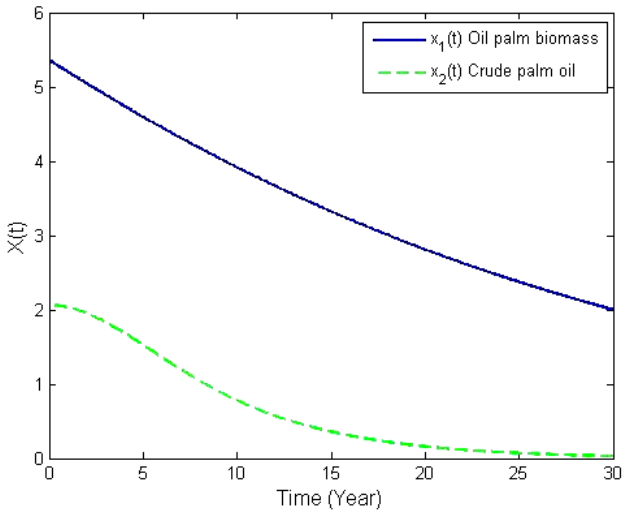


Figure 3 The optimal states

4.0 CONCLUSION

This paper presents a linear quadratic control model for oil palm plantation management. The model involves control functions of felling and harvest rates while biomass and crude oil are considered as state variables. The parameters of the model including, natural increase rate of oil palm biomass, influence on felling rate, crude palm oil production rate, and influence on harvest rate are estimated using a set of real data. This study provides the optimal felling and harvest rates in terms of an optimal feedback control valid for a limited time frame. Future studies are aimed to extend the proposed model for a long term control and management of the oil palm plantation system.

Acknowledgement

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