A Preliminary Study for Simple Physics Models of Coconut Tree

Rahmawati¹, HD Rahmayanti¹, N Amalia¹, S Viridi² and M Abdullah³*

¹Doctoral Program, Physics Department, Faculty of Mathematics and Natural Sciences
²Nuclear Physics and Biophysics Research Division
³Electronic Materials Physics Research Division
¹,²Institut Teknologi Bandung, Jalan Ganesha 10, Bandung 40132, Indonesia
²Research Center for Nanosciences and Nanotechnology, Jalan Ganesha 10, Bandung 40132, Indonesia
*E-mail: din@fi.itb.ac.id

Abstract. An investigation of how coconut palm tree withstands gale force winds has been performed. When observed carefully, the motion of the stalks and leaves affected the wind resistance. The stalks and leaves moved at random when intentioned wind blows. However, there is still no report on the physical modelling. This paper proposes a simple mathematical model to analyze the phenomenon. A simple tool was also designed to retrieve data using Video Tracker. The experiments were conducted on several types of springs. The model showed that the theoretical prediction accurately explained the phenomenon.

1. Introduction
The coconut tree (Cocos nucifera) is a member of the palm family which can be utilized for various purposes. Today, coconut trees are grown throughout the tropical world. Actually, there are many products that can be utilized using these trees. The uses of coconut tree from the leaves down to roots are main benefits. Therefore it’s often called the life of tree. In addition, an interesting physical phenomenon also to be investigated in coconut tree is withstanding gale force wind although this tree have no branches. When observed carefully, the motion of leaves and stalks to make effect of the wind resistance. Previous studies had examined the dynamics of motion for various trees and their resistance to the wind. James reported in which trees have been developed using mass damping when two or more coupled masses oscillate [1]. There have been also several studies on trees and winds and just focused on forest trees[2-5]. According to Moore dan Maguire, natural frequencies and damping ratio were main parameters in dynamic tree study to the wind [2]. Especially for tree branched, twigs get larger wind effect and braches to get smaller wind effect. Hence, should be considered these two aspects of influence to simulate the movement process of the tree [6]. The case studies focus on the phenomenon of natural frequency effect of coconut tree for the wind resistance. This research is expected to reveal the unique characteristics of coconut trees that can survive against strong winds though. Potential application in the future is to be a reference to design of earthquake resistant building construction.
2. Model
We assume that the natural frequency (without interruption) of the coconut palm oscillation is $\omega_0$. Change (deviation) at the natural frequency due to the change in the central mass location (because of leaves and stalks sway). Accordingly, natural frequency becomes time dependent. A slight change in natural frequency of the initial natural frequency (without the central mass location). Thus, the slightly natural frequency when the wind is blowing can be written:

$$\omega(t) = \omega_0 + \Delta \omega(t)$$

(1)

With $|\Delta \omega(t)| << \omega_0$ and has an average value $\langle \Delta \omega(t) \rangle = 0$ to ensure that the deviation is random. Thus, we can write the following expression of velocity

$$v(t) = v_0 \cos(\omega_0 t)$$

(2)

Then the kinetic energy of coconut tree can be written as follows:

$$E_k = \frac{1}{2}mv_0^2 \cos^2(\omega_0 t)$$

(3)

This study focused on the analysis of interesting phenomena in coconut trees when blown by the wind. This phenomenon is related to the physical parameters of oscillation, resonance event and energy from the random movement of the coconut’s stalks and leaves. The method is used physical model of the coconut’s stalks and leaves using spring-mass system. The phenomenon of oscillation motion had been recorded using a digital camera then analyzed using a video tracker.

3. Experiment
We assumed that the coconut tree is elastic and has varied leaves mass throughout its stalk. Based on the assumption, we made a simple model of coconut tree using elastic stems. The spring-mass system is representative of the coconut leaves are shown in figure 1.

![Figure 1. Simple model of palm coconut tree.](image)

In the experiments, we prepared four variations of spring-mass system model. First, for spring-mass system we used five equal masses and five springs with the same of constants of spring. Second, we used five different masses and five springs with the same spring constant. Then, we used five equal masses and five springs with different spring constant. The last variation, spring-mass system used five different masses and five springs with different spring constant. Furthermore, we provided external force on each model as a representative of the wind. Motions of manually released objects were captured for 60 seconds by digital camera (Nikon L840, 16 megapixel and 30 fps) in a video mode. Then, tracked every video recorded using video tracker and analyze the tracking results.
4. Results and Discussion
A simple model for experiment to investigated of natural frequency effect of coconut tree for the wind resistance has successfully been prepared using the spring-mass system, are shown in figure 2. We used four variations of spring-mass system model. The information about variations of spring-mass system model can be viewed in table 1.

![Image](image_url)

**Figure 2.** The result of pile driving tests at laboratory scale.

| Spring-mass System | Mass ($\times 10^{-3} \text{ kg}$) | Spring Constanta ($N/m$) |
|--------------------|----------------------------------|--------------------------|
| Type-A             | $m_1 = m_2 = m_3 = m_4 = m_5 = 5$ | $k_1 = k_2 = k_3 = k_4 = k_5 = 26.15$ |
| Type-B             | $m_1 = 15; m_2 = 20; m_3 = 5;$   | $k_1 = k_2 = k_3 = k_4 = k_5 = 26.15$ |
|                    | $m_4 = 50; m_5 = 50$             |                          |
| Type-C             | $m_1 = m_2 = m_3 = m_4 = m_5 = 5$ | $k_1 = 26.15; k_2 = 26.15; k_3 = 5;$ |
|                    |                                 | $k_4 = 138.75; k_5 = 27.75$ |
| Type-D             | $m_1 = 15; m_2 = 20; m_3 = 5;$   | $k_1 = 26.15; k_2 = 26.15; k_3 = 5;$ |
|                    | $m_4 = 50; m_5 = 50$             | $k_4 = 138.75; k_5 = 27.75$ |

We used four variations of spring-mass system model to analyze the effect of the behavior of the spring oscillation motion. We give external force on each model to represent the phenomenon of natural frequency effect of coconut tree for the wind resistance and then motion of models was captured by digital camera in a video mode. We used video tracker to analyze the video recordings data to observe the oscillation motion and angular frequency then visualize the motion oscillation in the coconut tree's physical model. Graph of angular frequency from video tracker analysis for all type of spring-mass system is shown in figure 3.
Based on figure 3, the angular frequency of spring mass system type-A; type-B; type-C and type-D begins to decrease drastically at t = 24s; 52s; 25s and 44s. A certain time interval affects the oscillation behavior of the real physical system. Its because of the non-conservative friction force in the medium where the system is immersed so that the amplitude of the oscillation decreases as energy is dissipated [7]. Therefore, this model can be represented motion oscillation motion of the coconut tree.

The relationship between the period and frequency of oscillations in the spring-mass system has been studied extensively by researchers for a long time [8,9]. Kinetic energy is the energy that an object possesses because of its motion. Kinetic energy is influenced by the mass of matter and its velocity. Graph of kinetic energy for all type of spring-mass system is shown in figure 4.

**Figure 3.** Graph of angular frequency on several spring-mass system (a)Type-A; (b)Type-B; (c)Type-C and (d)Type-D

**Figure 4.** Graph of kinetic energy on several spring-mass system (a)Type-A; (b)Type-B; (c)Type-C and (d)Type-D
All spring systems were damping when given external forces. From the four spring systems, the spring B system shows the oscillation motion which had the longest duration. The initial hypothesis predicts that the spring-mass system type-B with different mass variations and the same constants indicates the representative most approaching of natural frequency effect of coconut tree for the wind resistance.

5. Conclusions
The coconut tree’s physical model has been designed. The models consist of dynamic masses that represent the stalks and leaves. The phenomenon sway motion of the stalks and leaves as resistance to the wind represented by spring-mass system B. Further study is measured the natural frequency of the actual coconut tree, to compare the results of the experimental data on the coconut tree’s physical model. Then, it will be performed Monte Carlo simulations to predict the total energy of random motion of leaves and stalks. A simple tool will be also designed to retrieve data using Basic for Application (VBA) Excel.

References
[1] James K R, Dahle G A, Grabosky J, Kane B and Detter A 2014 Arboriculture & Urban Forestry 40(1) 1-15.
[2] Moore J R, and Maguire D A 2004 Trees 18(2) 195-203.
[3] Gardiner B, Byrne K, Hale S, Kamimura K, Mitchell S J, Peltola H and Ruel J C 2008 Forestry 81(3) 447-463.
[4] Cullen S 2002 Trees and wind : a bibliography for tree care professionals. J. of Arboriculture.
[5] Liu X, Xu Y, Zhai X and Xu W 2016 Int. J. Control autom 9(5) 375-386.
[6] Guitard D G E and Castera P 1995 Wind and trees 182-194.
[7] Triana C A and Fajardo F 2013 Revista Brasileira de Ensino de Física 35(4) 1-8.
[8] French A P 1971 Vibrations and wave. CRC press.
[9] Mak S Y 1987 American J of Phys 55(11) 994-997.