

THREE-DIMENSIONAL MODELING OF A TROPICAL TREE, MELALEUCA SP, USING THE DIGITAL PHOTOGRAMMETRY

K. Yoshino^a, B. Okarda^b

^a Graduate School of Systems and Information Engineering, University of Tsukuba, Japan, - sky@sk.tsukuba.ac.jp

^b Forest Watch Indonesia, Bogor 16129, INDONESIA - b.okarda@gmail.com

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ABSTRACT:

Dynamic modelling language for three-dimensional simulation has been used in various academic fields. Modelling tree growth constructs natural tree shapes or canopies in three dimensions based on several stand structural parameters. Many researchers have tried to simulate tree growth in various approaches. One of them is L-System developed by Lindenmayer in 1968. L-System describes the fractal branching structure of trees based on the local production rules, which are applied iteratively and simultaneously to create a complex branching system in simple grammar language. The three-dimensional model of trees is developed to fulfil research needs, such as estimating Leaf Area Index (LAI), canopy structure, and tree biomass, in simulating tree structures and canopy shapes as the tree grows under different environmental conditions. They could be useful to understand the physical responds of trees on environments.

In this research we developed a three-dimensional tree model of *Melaleuca* sp. This species of tree is known as a rehabilitation plant which can grow under various environmental conditions such as drought or flood. The structural parameters of trees for modelling are derived from the photogrammetric measurements and input into L-System for the three-dimensional tree model. The result from this research would be a basic research to understand the physiological and ecological responses of *Melaleuca* sp tree s for different environmental condition.

1. BACKGROUND

Researches on 3D tree shape modeling have had remarkable progresses along with advancement of computer graphic technology. Computer graphics has been used for the modeling, simulation, and rendering of trees and plants for decades. One of those computer algorithms named L-System, developed by biologist Aristid Lindenmayer in 1968, has improved significantly. L-System is based on the mathematical theory to model the processes of plant growth. The grammar to describe the algorithm for modeling tree stand structures is fairly simpler than the English grammar. A computing language produced by that grammar is expressing one of the model of the tree stand structure based on geometrical and topological characteristics of plants or trees (Merril, 2000). The principal concept of L-System is to describe complex objects by successively replacing some parts of a simple initial object as following a rule of reproductions (Prusinkiewicz and Lindenmayer, 1990). L-System allows specification of the way how an object transforms from one state to another, or sometimes adds new parts for an initial interval. Particular plant parts in specific state are described by the symbols and processes of transformation which are expressed by morphogenetic rules or equations to imitate plant shape (de Visser et al, 2002).

The genus *Melaleuca* consists of 200 woody species, all growing in Australia only, except one species, *M. leucadendron* which is distributed in Southeast Asia to New Guinea, Australia, and New Caledonia. It is sometimes divided into 10 species. The species in Southeast Asia is often named *M. cajuputi* Powell. That tree is small to medium-sized tree, 15-25 m tall, 20-50 cm in diameter, and usually grows in swamp forest bordering of the mangrove, often in pure stands, but sometimes

also found in savanna forest in the Moluccas and New Guinea (Ogata et al, 2008). Genus *Melaleuca* was known as fire tolerant species easily sprouts after fire. It often regenerates in burnt area, and usually selected as rehabilitation plant in swamp and peat land area. *Melaleuca cajuputi* has been used in peat reclamation in Indonesia since 1970 because this species can grow in unfertile soil, acid soil, soil with less oxygen and submerged soil (Dharmono, 2007). Moreover, *Melaleuca* leaves produce essential oil which contains cineol used as medicine oil and known as Cajuput oil. And also, *Melaleuca* can produce timber up to 5.986,56 m³ per year per hectare (Dharmono, 2007). It is important to understand the *Melaleuca* tree's responses to environmental changes and growing processes with adaptation to the environment. The stand structure of *Melaleuca* trees informs tree's responses or adaptations to environmental changes. The models of three dimensional tree stand structure will be useful for solving these topics.

2. METHOD AND DATA

In this work, we used a close-range photogrammetric which combine with L-System (details are described in **APPENDIX**) to obtain structural data of *Melaleuca*. and developed the three dimensional tree stand structure models. Close range photogrammetric is used for stereo-viewing view and to measure 3D coordinates of twigs, branches and a trunk of the sample tree. Using photogrammetry, angles between two twigs or branches and length of twigs or branches, which are recorded on the films or digital photos, can be measured. However, the photogrammetry has a highly complex process because of the imposing dimensions and of the complex geometries of the architecture (Kasser and Egles, 2002). In close range

photogrammetry, the pictures are taken using several cameras facing the target object settled at different positions in order to obtain a three-dimensional instantaneous view. The procedure is essentially similar to that used in mapping from aerial photography except that cameras are fixed and different positions of cameras leads to displacement in successive photographic images (Wood, 2004).

Figure 1 shows the sample image of a *Melaleuca cajuputi* tree for this study that was taken at the tropical peat land in the southern Thailand in 2006 August.



Figure 1 *Melaleuca cajuputi* tree for this study

In this research, the segment length, angle, and diameter from main stem up to the third order branch were measured. Angles between twigs are important parameters that will drive the tree shape model orientation into the realistic shape of tree. Angles between twigs or branches are computed from three-dimensional coordinates of a pair of twigs/branches using cosines rule(Eq.1). These 3D coordinates of end points of segments are measured in three points in parent branch, intersection point between parent branch and branch, and in branch itself. Due to irregular structure of an actual tree stand, the locations of coordinate sampling points are chosen by visual observation of stereo images.

$$\cos \theta = \frac{AB^2 + AC^2 - BC^2}{2AB \cdot AC} \tag{Eq.1}$$

Length of the segment is also measured by computing distance between a pair of end points(P1 and P2) of the segment on branch and main stems following the formula in (Eq.2). Point samples are put on each segment node throughout branch. The distance between end points represents the segment length and summation of these distance will be the branch length.

$$P1P2 = \sqrt{(x2 - x1)^2 + (y2 - y1)^2 + (z2 - z1)^2} \tag{Eq.2}$$

Furthermore, the correlation between branch lengths and diameters of branch is to be studied. At the same time, the

correlation between distances from base stem to stem shoot and the diameter is to be studied, too. The correlation which shows a simple linier regression model and simple statistical result means correlation with tree stand shape. Tree components measured through stereo photogrammetry can be used to develop a 3D tree stand model with L-System approach.

3. RESULTS

Using stereo photogrammetry, we got several tree structural parameters. These parameters were calculated based on processes described above. The results showed the tree structural parameters in each category. **Table 1** and **Figure 2** show the descriptive statistics of structural parameters of the main stems and the relationship between the height of the stems and diameters. **Figure 2** shows the distinct linear relation.

Table 1 Descriptive statistics of the main stem

Main Stem	Diameter (m)
Average	0.0065
Min	0.0011
Max	0.0168
SD	0.0129
N	76

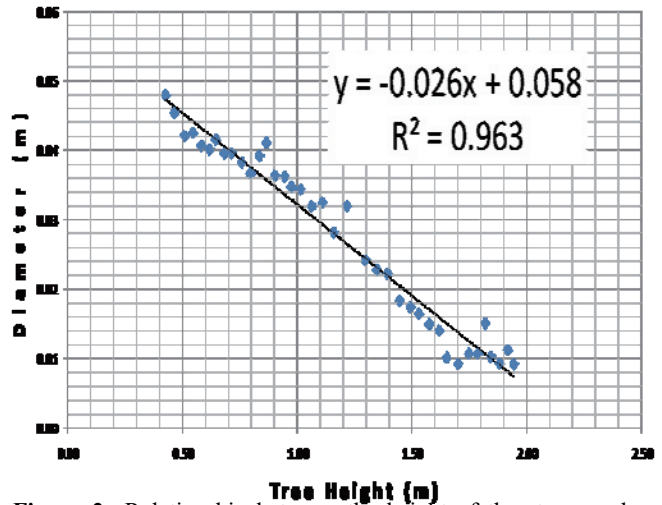


Figure 2 Relationship between the height of the stems and diameters

Table 2a,2b,2c shows descriptive statistics of structural parameters of the first, the second and the third stems, respectively. **Figure 3a,3b,3c** show relationships between the stem length and the diameter in stem order levels.

Table 2a Descriptive statistics of structural parameters of the first stems

1st Order	Length(m)	Diameter(m)	Angle(deg.)
Average	0.2331	0.0065	55.24
Min	0.0904	0.0011	12.68
Max	0.370	0.0168	97.35
SD	0.0935	0.0035	23.03
N		76	18

Table 2b Descriptive statistics of structural parameters of the second stems

2nd Order	Length	Diameter	Angle
Average	0.2016	0.0029	47.83
Min	0.1091	0.0007	16.17
Max	0.3243	0.0058	100.41
SD	0.0791	0.0011	18.70115
N		88	40

Table 2c Descriptive statistics of structural parameters of the third stems

3rd Order	Length	Diameter	Angle
Average	0.1593	0.0026	47.77
Min	0.0904	0.0006	18.89
Max	0.3070	0.0044	94.24
SD	0.0007	0.0007	15.09
N		74	45

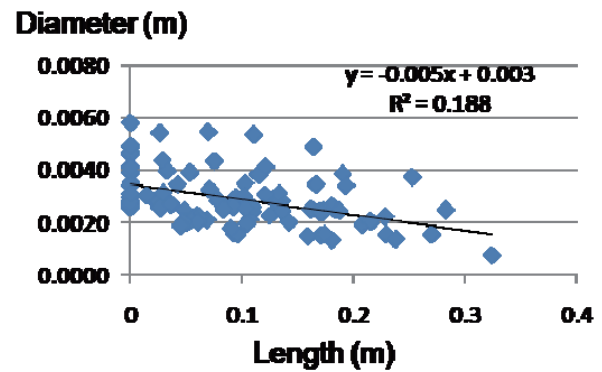


Figure 3b Relationships between the stem length and the diameter in the second order stems

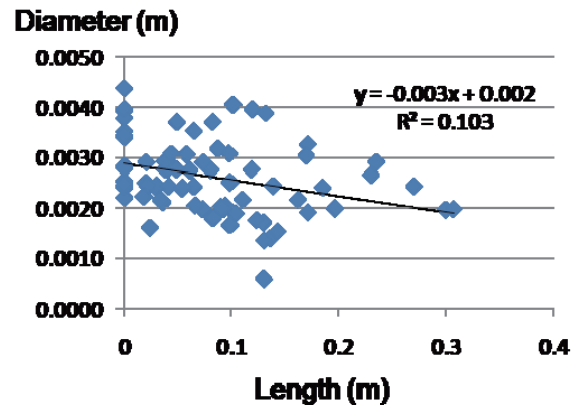


Figure 3c Relationships between the stem length and the diameter in the third order stems

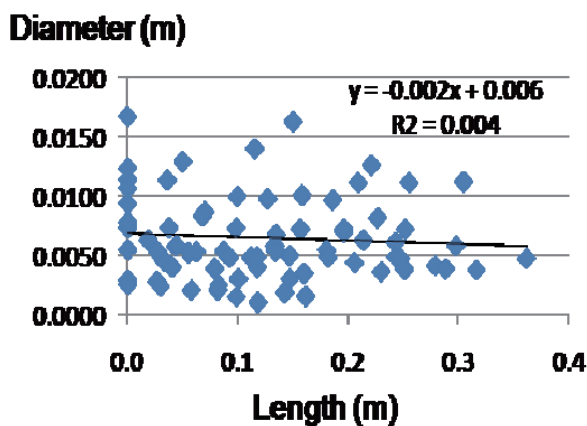


Figure 3a Relationships between the stem length and the diameter in the first order stems

Table 3 Results of Specific Leaf Area measurement

Sample	Weight (g)	Leaf Area (m2)
A	1	5.5426E-02
	2	9.1964E-02
	3	9.7436E-02
	4	6.5310E-02
Sub Total	114	3.1014E-01
B	1	1.1510E-01
	2	1.0637E-01
	3	7.4652E-02
Sub Total	115	2.9612E-01
C	1	9.9733E-02
	2	8.3131E-02
	3	8.8570E-02
	4	4.0588E-02
Sub Total	114	3.1202E-01
Total	343	9.1828E-01

The leaf area from tree sample were also measured. Specific Leaf Area is calculated with leaf area and leaf weight. The average leaf weight is resulted $0.0374\text{g}/\text{cm}^2$ of a single leaf. In advance, this result is helpful to estimate the biomass of tree. **Figure 4** is one of the photos of sampled *Melaleuca* leaves. The red circles are references for area computation from images. **Table 3** was the results of specific leaf area from sampled photos. As the total weight of leaves of the *Melaleuca* tree in **Figure 1** was 1141g, the total leaf area of that tree was 3.051m^2 . It means the LAI was about 3.



Figure 4 Melaleuca leaves

Inputting all the structural parameters measured in this study into the L-System package, the model tree of the *Melaleuca* was created as shown in **Figure 5** and **Figure 6**. **Figure 5** and **Figure 6** were the side view and the nadir view of the model *Melaleuca* tree imitated the true tree. In **Figure 5**, it looks a very similar tree at the field.

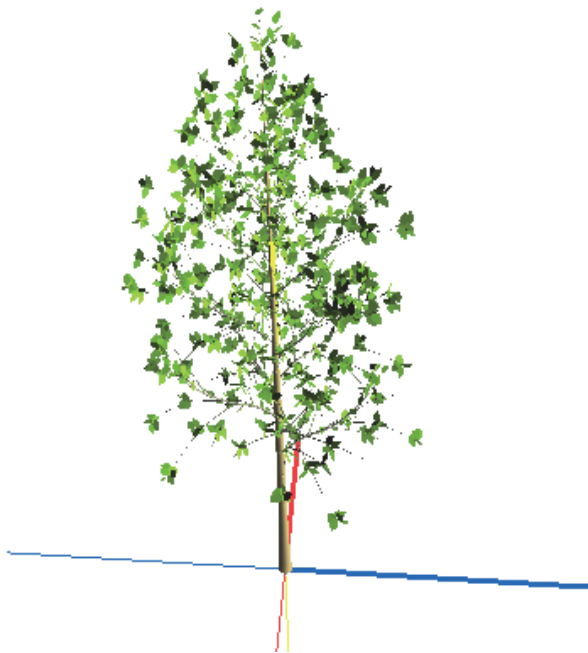


Figure 5 Side view of Melaleuca model

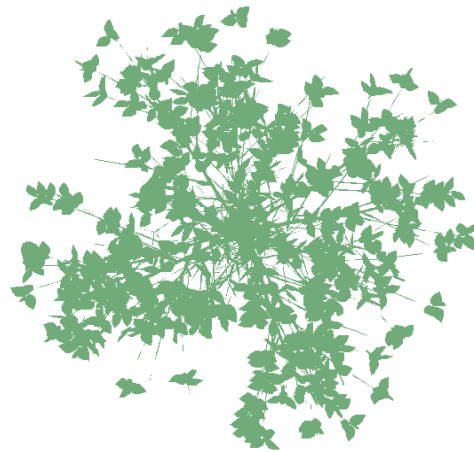


Figure 6. Nadir view of Melaleuca model

4. DISCUSSION

The results show that structural parameters vary so largely, except those in the main trunk. In angle measurement, branches of all orders also have wide range of variety. In order to get parameter value to input into L-system model, each parameter is to represent the average value, and also to have good relationship between angle, diameter, and height. In branch order of the 1st, 2nd, and 3rd, the value of R^2 for correlation between length and diameter are ranging from 0.4% to 18.8% with a large standard deviation indicates that each branch measured has various values of length and diameter.

Lengths of branch are measured from base of stems or upper branch order up to stem shoots. These result shows no significant correlation between branch length and diameter of branch in all branch orders. In general, the linier regression of diameter is showing the descending trend in small number from base stem to stem shoot. The correlation between height and diameter are shown in main stem measurement. R^2 was 0.963 in linier regression analysis. Considering this result, the significant correlation between height or length to diameter in tree stand structure can be only clearly seen in the main stem. As all statistical results, it can be said that the sample tree of this species had some kinds of irregular stand structure. Some of the branches grew in the lower part is younger than in upper part of tree and some branches in the upper part of tree have bigger diameters than in the lower part.

The three-dimensional model produced by L-System uses the average values of each parameter which represent parameters of regular structures without considering any other environment effect. L-system produced the 3D tree stand model using with stand parameters of the main stems, three orders of branches and leaves. The lengths of the main stem and branches follow the structure functions obtained from the former measurement. The branches in the first order came out from the main stem node and also grew base on the function from photogrammetric measurement. The orientation of branches is determined by the orientation of the parent branch with the average angle parameter in the branches in the first order. This orientation angle defines the shape of the tree crown. Doran (1999) said *Melaleuca* crown usually dense and wide. *Melaleuca* crown of

this model shows less dense and does not so wide. This probably happened because the tree sample used for this model is young tree. The branches in the second order were produced using the first order branches as parent branches and the third order branches were also produced using the second order branches as parent branches. Leaves were inserted in branch internodes. Leaves were separated by the branch function and inserted in the second and the third order branches. Determination of the average number of leaves and their distribution in each branch still need further researches.

5. CONCLUSION

The result of this research shows various ranges of parameters of tree stand structure. These values of parameters show enormous structural complexity of natural plant growth. As this tree model produced in this study was based on the parameters from a single sample tree, the imitated tree model may not exactly describe *Melaleuca* trees in general, but this model tree can be used as preliminary research for further advance researches. In future, this research can be improved with additional environmental variables in different conditions to express the effects of environment conditions on the growth and tree stand structure of *Melaleuca* trees.

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APPENDIX

L-System (Lindenmayer systems) are mathematical tools to imitate plant development and stand structure that are described by a simple algorithm in order to define complex objects by successively replacing parts of a simple initial object using a set of rewriting rules or productions (Prusinkiewicz and Lindenmayer, 1990). L-System uses a grammar-based modelling technique. Its grammar is much simpler than the language grammar such as English grammar. Scripts produced by that grammar describes a geometrical and topological structure of plant stands (Merril, 2000). It specifies the transformation of an object from one state to another, sometimes adding new parts for a pre-defined interval. Particular plant parts under specific state are represented with symbols and processes of transformation following morphogenetic rules or equations (de Visser et al, 2002). The illustrations below show the concept of L-System which describes the plant development and tree stand structure, and its process and grammar.

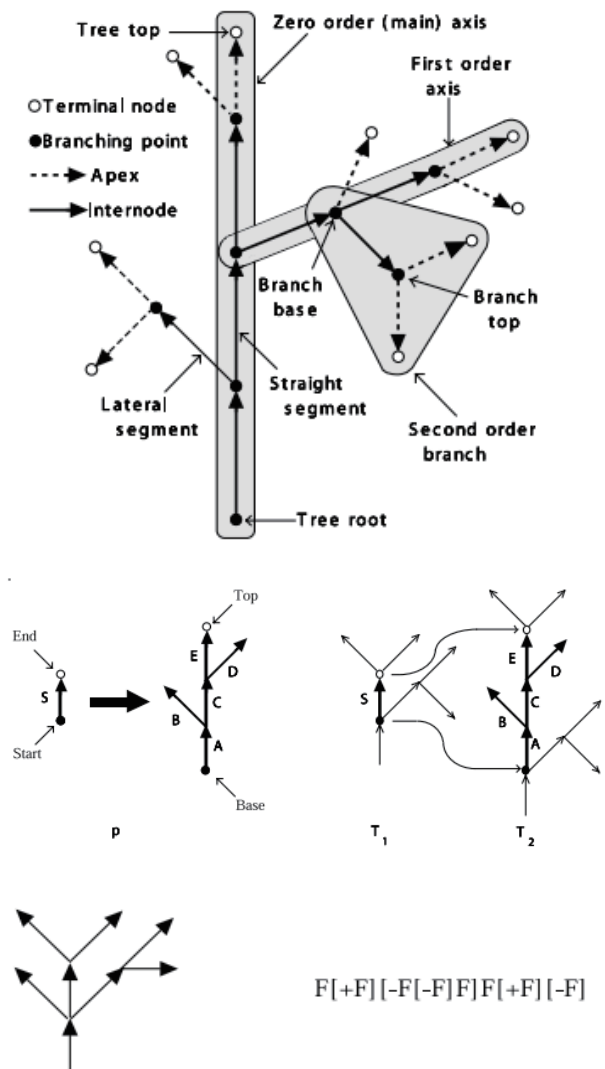


Illustration of the concept of L-system