Research of Leaf Quality Based on Snowflake Theory

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***Abstract*—To study the leaves quality, this paper proposed two efficient models to analyze leaf quality, which classify leaves based on different shapes, leaf shapes were classified from the macro and micro perspectives respectively. In the two perspectives, influential factors were extracted and analyzed by factor analysis and K-means clustering. After comparing clustering result with actual classification result, misjudgment probability is found to be very low. In the second model, snowflake model theory was proposed. The theory is high similarity between snow structure and tree structure, and the formation of the branch copies the exterior characteristics of the backbone. Then the growth process of a tree was simulated, after calculating the number of smallest branches through programming, the total number of leaves could be calculated out. To estimate the tree leaf weight, two steps were divided. First step was to estimate the number of leaves using the snow theory. Second step was to estimate the area of single leaf. Finally, the area measurement model to flat leaf was set up to measure the area of the curly leaf, which was dividing the whole curly leaf into small pieces.**

***Index Terms*—factor analysis, snowflake theory, misjudgment probability, error evaluation**

I. INTRODUCTION

Leaves are the material basis of photosynthesis, the “green factory” producing nutrients, and the medium of transpiration [1, 2]. It is not only the important factors of the growth of trees, yields of leaves and species characteristics, but also the important means for reasonable cultivation and management of trees and detection of occurrence and development of plant diseases and insect pests [3, 4]. So leaf area is the constant consideration in the physiological and biochemical research, genetic breeding, cultivation, etc., of trees [5]. In trees cultivation, leaf area index is commonly used to weigh the trees group's growth, which is used as the referential index for determining cultivation measures [6, 7]. In addition, the determination of leaf area ate by pests is the important content of studying pest damage loss. And accurate measurement of leaf area is the premise of studying leaf area [8].

There has been a variety of algorithm for determining surface area of a single leaf. Direct measurements have been made by many scholars with instrument measurement method, paper drawing method, digital image processing method [11, 12], experience formula and volume method. Leaves are divided into two types, i.e., needle-leaved tree and broad-leaved tree, for which different methods should be taken to measure surface area of their leaves. The measurement of leaf surface area with instrument method is simple and quick in operation. Structure used in the measurement could be divided into two types: one is leaf area structure and another is planimeter [13]. In paper drawing method, leaves are spread out on flat paper with well-distributed coordinates and outline of the leaves are drawn on the paper [14, 15]. After that grids occupied by each leaf are counted to calculate surface area of respective leaf. A full grid is counted as an area unit and less than a full grid is counted according to the proportion occupied by the leaf in the grid, i.e., $1/2$, $1/4$ etc.

There is a variety of shapes for leaves [16]. Leaves are the largest organ of trees exposed to air, with the largest contact area to outside environment. Therefore, environmental conditions have a significant impact on shape and structure of leaves. In the evolutionary process trees adapting to different ecological environment, a variety of ecological types of leaves is shaped. In dry climate and drought environment with the lack of moisture in soil, in order to adapt to drought environment, the leaf structure characteristics of trees growing in arid regions is working towards two aspects of development, i.e., reducing transpiration and saving water [17, 18]. Thus leaves of those trees are usually small to reduce transpiration of leaf area.

Stout branches could withstand larger pressure, and farther the branches are away from the branch nodes the shorter and thinner they are [7]. The thinner the branches are, the lighter the weight born by the branches is and the smaller the leaves are. The longer the length to branch nodes on the same height to the ground is, the bigger the shapes of leaves are [8, 9]. Compared with leaves on branches from the same class of branch nodes, leaves on branches lower to the ground are bigger to enhance

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photosynthesis for weak sunlight they receive [10, 11]. Therefore, the distribution of leaves on trees and branches affects the shape of leaves.

In 1999, experts have made research into branching angle of trees with statistical method, founding that branching phenotypes of trees is the mutual effect of genetics and environment [12, 13]. Tree species using 30^0 as basic branching system includes: Pinnata, Spend Pear, Sapindus , Hong Kong Quebracho, Chung Yeung Wood, etc. Tree species using 60^0 as basic branching system includes: White Lam , Phoenix Wood , Crabapple Tree , Large Leaves Shi Li, etc. Tree species using 90^0 as basic branching system includes: Hainan Indus, Homalium Hainanense, Gentianales [14, 19, 20]. The bigger the branching angles of the trees are, the larger the leaves are. According to statistical data analysis, the bigger the branching angles are, the larger the crown of the trees are. Because the sunlight shining intensity of the lower leaves is weak, in order to increase photosynthesis, the shape of leaves become larger. So the shape of crown of trees affects the shape of leaves. The shape of leaves (general characteristics) is correlated to the outline and branching structure of trees.

In recent years, the use of mathematical model to predict leaf area has become a very common method [7, 17, 20]. With linear model, Robert Rogers Thomas M. Hinckley has made a research into the relationship between leaf weight and area of oak species and sapwood produced in the same year by the same tree (expressed with CSA). According to the research, the relationship is highly correlated in yellow oaks and white oaks. Through the research into the relationship between leaf area and chest diameter of arbors and shrubs, Kittredge has successful completed the fitting of leaf area and chest diameter regression equation. With BP artificial neural network, related work has effectively predicted the cucamultion volume of standing forest in Greater Khingan Range in [3, 13]. BP neural network method has been used to solve the problem of leaf shape classification, resulting in an accuracy of 86.67%. However, mathematical model is seldom used to in-depth research of leaf shape classification.

To study the leaves quality, this paper proposed two efficient models to analyze leaf quality, which classify leaves based on different shapes, leaf shapes were classified from the macro and micro perspectives respectively. In the two perspectives, influential factors were extracted and analyzed by factor analysis and K-means clustering. After comparing clustering result with actual classification result, misjudgment probability is found to be very low. The second model is based on snowflake theory, which is high similarity between snow structure and tree structure, and the formation of the branch copies the exterior characteristics of the backbone. Then the growth process of a tree was simulated, after calculating the number of smallest branches through programming, the total number of leaves could be calculated out. To estimate the tree leaf weight, two steps were divided. First step was to estimate the number of leaves using the snow theory. Second step was to estimate the area of single leaf. Finally, the area measurement model to flat leaf was set up to measure the area of the curly leaf, which was dividing the whole curly leaf into small pieces

II. Proposed Classification Model

A. Terms Explained

• Ground Diameter: Diameter of the trunk about 20cm from the ground.

• Breast Diameter: Diameter of the trunk about 1.3m from the ground.

• Clear length: height of trunk below minimum branches of the crown.

• Crown of a Tree: The part above the trunk of an arbor tree bearing branches and leaves, like a crown.

• Class 1 branch: Class 1 branch is the framework of a tree, the length and special arrangement of which plays a dominant role in shaping the tree. It has a certain growing position and azimuth attributes on the trunk.

• Node Sections: Sections dividing by nodes on class 1 branch.

• Section Spacing: Distance between each layer of class 1 branches.

• Azimuth: The horizontal angle between each class 1 branch and horizontal plane in verticality to the trunk.

• Branch Angle: Vertical angle between each class 1 branch and vertical plane parallel to the surface of the trunk.

• Curvature: Curving degree of class 1 branches.

• Physiological Age: is a concept comparing with growth age, representing plant life vitality, and could be distinguished according to the change of the structure of plant shapes. When the physiological age of the lateral branch is the same to that of the trunk, it is called "repeated growth" phenomenon, which accord with our hypothesis in snowflake theory.

B. The Classification Model of Leaves 1

For trees, there are internal and external causes affecting their leaves shape, but the internal and external causes all have a variety of factors, such as for internal causes there are genes, ways of transportation, and mutation, etc.; for external causes there are sunshine, moisture, temperature, change of worms, and soil etc. Therefore, classification for leaves shapes is a complex and delicate job. Our analysis is mainly carried out from two perspectives, i.e., macro and micro perspectives.

The theoretical result shows that the shape of leaves is not only determined by their growth genes but also affected by growth environment, growth shape and growth scale of the trees. From this perspective, certain influential factors of the shape of tree leaves could be chosen as the indexes. According to relevant material, factors describing shapes of trees include: ground diameter, breast diameter, tree height, clear height, average crown diameter, south-north crown length, east-west crown length, layers, internodes spacing, etc. According to the nine factors cluster analysis is made on trees to classify the similar growth shapes into one category. But it just makes a rough analysis on leaves shapes, so the next step is refined analysis.

C. Classification Model of Leaves 2

Then factor analysis is made on tree leaf shapes within one category to calculate factor score, which is used for clustering. This kind of clustering analysis method is refined. We know that there are several dozens of factors describing leaf shapes, such as leaf shape, leaf width, leaf length, leaf vein, etc., but we know that the length of veins in a certain extent determines leaf length and leaf width. And some factors could be completely described by other factors, so we use the method of reducing dimension firstly and then clustering. We use factor analysis to reduce the dimension of influential factors to get factor score for clustering. This method not only can distinguish well leaf shapes, but also can reduce the complexity of the analyzed problem.

The mathematical model for factor analysis is as follows:

$$\begin{cases} X_1 = a_{11}F_1 + a_{12}F_2 + \cdots + a_{1m}F_m + \varepsilon_1 \\ X_2 = a_{21}F_1 + a_{22}F_2 + \cdots + a_{2m}F_m + \varepsilon_2 \\ \vdots \\ X_P = a_{P1}F_1 + a_{P2}F_2 + \cdots + a_{Pm}F_m + \varepsilon_P \end{cases}, \quad (1)$$

represented with matrix:

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_P \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{P1} & a_{P2} & \cdots & a_{Pm} \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_m \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_P \end{bmatrix}.$$

Simply recorded as:

$$X = AF + \varepsilon . \quad (2)$$

And meet:

1) $m \le P$;

2) $\mathrm{cov}(F, \varepsilon) = 0$;

3) $D(F) = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} = \mathrm{I}_m$;

$F_1, \cdots, F_m$ is unrelated and variance are 1.

4) $D(\varepsilon) = \begin{bmatrix} \sigma_1^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_P^2 \end{bmatrix}$.

$\varepsilon_1, \cdots, \varepsilon_P$ denote unrelated and different variance.

Among them is the P dimensional random vector as unobservable volume, comprised by P indexes got in actual observation. $F = (F_1, \cdots, F_m)'$ is called common factor of $X = (X_1, \cdots, X_P)'$ the above-mentioned integrated variable. A is factor loading matrix, on which maximum variance rotation is made with variance, so that the structure of A simplified. In other words, the square value of every column elements of loading matrix is made to polarization 0 or 1 or the more dispersed the contribution rate of public factor is the better is the result. Variables got from factor analysis are represented as linear combination of public factors:

$$X_\mathrm{i} = a_{\mathrm{i}1}F_1 + a_{\mathrm{i}2}F_2 + \cdots + a_{\mathrm{i}m}F_m + \varepsilon_\mathrm{i}$$
$$\mathrm{i} = 1, 2, \cdots, P \quad (3)$$

But usually when public factors are used to represent the original variables, it is more convenient to describe the characteristics of research object. Therefore, public factors are represented as linear combination of variables, i.e., the factor score function, namely

$$F_\mathrm{j}' = \beta_{\mathrm{j}1}X_1 + \beta_{\mathrm{j}2}X_2 + \cdots + \beta_{\mathrm{j}P}X_P$$
$$\mathrm{j} = 1, 2, \cdots, m \quad (4)$$

We calculated m factor score for each left samples. Use the score of these m factors as a variable value to cluster different leaves with the method of K-means Cluster.

D. Clustering Error Estimation

We have given the evaluation method for judging clustering effect. Usually we use back substitution misjudgment probability and cross misjudgment probability. If the number of misjudging samples belong to G_1 as belong to G_2 is N_1, and the number of misjudging samples belong to G_2 as belong to G_1 is N_2, the total number of samples of the two general classifications is n, Then misjudgment probability is:

$$p = \frac{N_1 + N_2}{n} \quad (5)$$

Back substitution misjudgment probability

Set G_1, G_2 as two general classifications, $X_1, \cdots, X_m$ and $Y_1, \cdots, Y_n$ are training samples from G_1, G_2 respectively, with all the training samples used as $m+n$ new samples, which is substituted gradually into established criterion for judging the ownership of the new samples. The process is called back substitution. If the number of misjudging samples belong to G_1 as belong to G_2 is N_1, and the number of misjudging samples belong to G_2 as belong to G_1 is N_2, then misjudgment probability is:

$$\hat{p} = \frac{N_1 + N_2}{m + n}$$

Cross judgment probability

Back to generation misjudgment probability is to eliminate a sample every time, and use the rest of $m+n-1$ training samples to establish a criterion for judgment, then use established criterion to make judgment on deleted samples. The above-mentioned analysis is made on each sample of those training samples, and uses its misjudgment proportion as the misjudgment probability. The specific procedure is as follows:

1) From training samples in general classification G_1, eliminate one of the samples, and use the rest of the

samples $m-1$ plus all samples in G_2 to establish discriminate function;

2) Use the established discriminate function to make judgment on eliminated samples;

3) Repeat steps 1), 2) until the samples in G_1 in turn be deleted and judged. The number of misjudged samples is recorded as m_{12} ;

4) Repeat steps 1), 2), 3) for samples in G_2 , until all of the samples in G_2 in turn be deleted and discriminated. The number of misjudged samples is recorded as n_{21} . So cross misjudgment probability is estimated:

$$\hat{p} = \frac{m_{12} + n_{21}}{m + n} \tag{6}$$

If clustering result is bad, the following several aspects of optimization could be carried out. 1) Increase sample capacity; 2) Increase new index variables; 3) If statistical data is wrong, rediscover data.

III. Proposed Model based on Snowflake Theory

A. Snowflake Theory

Each snowflake on the whole is a hexagonal star, in which there are six trunks, and then each trunk has small branches, and smaller branches growing on small branches, and so on, as shown in figure 1 below. The process of shaping snowflake is copying part and the whole sections of it constantly. The process with the above mentioned of growth characteristics is called snowflake theory.

Figure 1. Snowflake

We already know in the above that each tree species has its own particular branching angle. We think of tree trunk as straight, and from another perspective, we could see it as a lateral branch. We all know that each lateral branch has the function of branching, and all of the lateral branches have the same status. Each layer of the branches will branch in accordance with certain similar rule. According to this growth rule, we simulate the outline of a tree, as shown in Fig. 2.

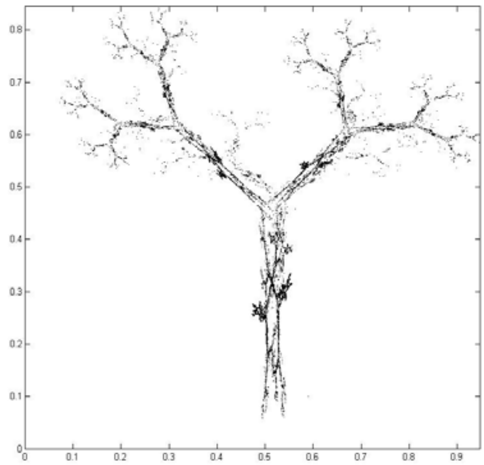

Figure 2. The Tree of Computer Simulation

According to the ideas of snowflake theory, the growth process of trees is established until it reaches the state of the tree for observation. The laws of changing between the state of a certain level of branching and the state of its sub-level of branching should be found out to for the recursion relationship of programming. Among a certain level of branch the main parameters are the quantity of branches, number of sections, interval of sections, azimuth, included angle of branching, curvature, length of branches, and stem. In [1] three ways of branching have been mentioned, i.e., single axis branching, false binary branching and merging axis branching. To simulate the growth of a tree, which way of branching it belongs to should be found .Then after finding out the law of its branching, computer could be used to simulate out its growth process.

B. Ways for Branching

We have known that the growth process of trees has the characteristics of self-adaptive, uncertainty, emergency, finality and opening. Different kinds of trees have different ways of branching, and the law of copying is different. So we will analyze ways of branching. Roughly there are three ways of branching for trees:

• Single axis branching: The apical bud of the tree constantly grows up vigorously, shaping the stout trunk. And lateral buds also grow into the lateral branch, on which sub-branches grow again, as shown in figure 3 below. The trunk of single axis branching is comparatively straight, and the growth of other branches at all levels is not so vigorous as it. Poplar, metasequoia, etc., are all within the group of single axis branching.

False binary branching: The apical bud of the tree stops growing after shaping a branch. Close to the branch two opposite auxiliary buds simultaneously grow into a pair of opposite lateral branches. Then the apical bud and auxiliary buds on the two opposite lateral branches repeat the same growing process, as shown in the figure below. Clove, carnation and horse chestnut, etc., are all within the group of false binary branching.

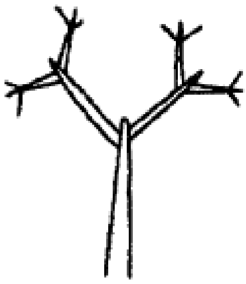

Figure 3. Single Axis Branching

Figure 4. False Binary Branching

Merging axis branching: The growth rate of apical bud of the tree slows down or the apical is dead or become flower bud. The auxiliary bud immediately under the apical bud replaces the growth of the apical bud to shape a branch. After that the apical bud of the branch stops growing and replaced by the auxiliary bud immediately under it. The growth process is repeated. The length of node section of merging axis branching is comparatively short, often with a tortuous shape, as shown in the figure below. Apple, pear, peach and apricot trees, etc., are all within the group of merging axis branching.

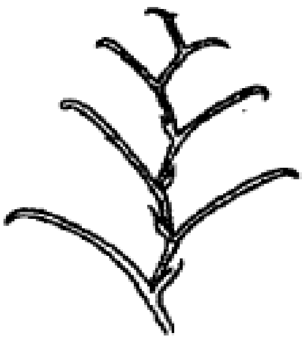

Figure 5. Merging Axis Branching

C. Establishment of Models

Model assumptions are as follows:

• In the growth process of the trees, abundant nutrients are supplied for the growth of each auxiliary bud.

• In the growth process of the trees, no lateral branch dies.

• Environmental factors shouldn't increase (decrease) to the highest (lowest) point so that to block the normal growth of the plants.

• In the growth process of the trees, the branching angle of float from a certain range.

• In the growth process of the trees, along with the increase of the layer of branching, branches become tapered, and length of branches gradually becomes short.

From a macro point of View l, trees have one thing in common in the composition of it's shape and structure, namely the basic constructing element of trees are trunks, branches and leaves. The structuring of each basic element is following a same way: the trunk gives birth to the first layer of branches, which in turn gives birth to the second layer of branches, and so on. The process of giving birth eventually comes to leaves. In the occurrence and development process of the shape of the trees, organizations similar to the existing organizations are constantly copied and added to the existing ones.

Based on the above-mentioned cloning process, eight basic parameters are used to be defined the structure of branches, as shown in Table 1.

TABLE I.
EIGHT BASIC PARAMETERS

Layer	Layers of tree	[2, 8]
H	Height of branches	[0.0, 1.0]
R	Bottom radius of branches	[0.0, 1.0]
Alfa	Branching angle	[0, 90^0]
K	Rattion of top and bottom radius	[0.0, 1.0]
P	Height of branching point	[0.0, 1.0]
Q	Attennuation of thickness of branches	[0.0, 1.0]
M	Attennuation of lenght of branches	[0.0, 1.0]

Because of the influence from many kinds of factors such as gravity, wind and sunshine, etc., In the process of their growth, the growth shape of trees in nature has got great uncertainty and randomness. In order to describe shapes of trees more vividly, in the process of establishing mathematical model stochastic function is introduced. Following is a maple tree simulated with a computer model, as shown in Fig. 6 and Fig. 7:

Figure 6. Simulation of maple.

From the simulation rendering with computer, we can find out that the similarity degree between the simulated image and maple tree in real life is very high. Visibly, the reliability of estimating leaves number with the use of snowflake theory is very high.

Figure 7. simulation of maple tree

IV. SINGLE LEAF AREA ESTIMATION

Ideas of model: we have classified leaf shapes in the above, so when we want to establish the model for leaf area estimation, we can find a representative leaf for analysis. In the process of analysis, mainly ideas of integration are used, in which, a reasonable division is given to leaves in different shapes in order to divided them into graphics, of which areas can be calculated for analysis; Also considerations are gave to the bending problem of edges of leaves when the veins become closer to the central line at the middle of the leaves. For the calculation of this model each leave is segmented along with the veins of the leave.

A. Flat Leaf

Take a typical leaf, and draw its shape on a piece of a coordinate paper. Take some points from the drawing and make a fitting to work out the leaf outline function with Least squares method. We can get the function images as shown in figure 8.Then we can calculate the leaf area S with curvilinear integral:

$$S = \int_{x_1}^{x_2} f_1(x)\,dx - \int_{x_1}^{x_2} f_2(x)\,dx \tag{7}$$

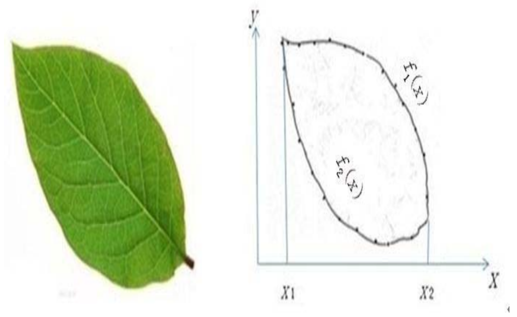

Figure 8. The simulation of flat leaf

B. Curving Leaf

Through observation we can find out that most of the curving of a leaf follows the vein and towards the middle line, and the curving is gentle. The appearance of a bigger arc of curving is unusual, so we suppose that the curvature angle following the vein is very small, and we divide leaves with this kind of features as shown in figure 6(This is divided along the veins on the leaves), with the hypothesis that the rectangle divided out by us is in a plane.

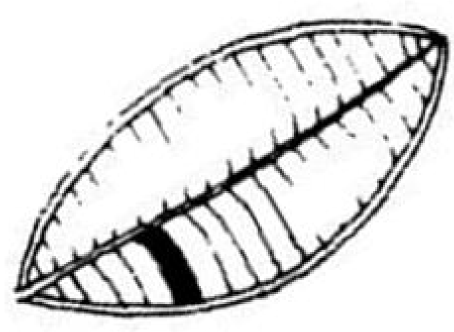

Figure 9. The division of curving leaf

This model can only make a rough estimation of the area of the curving leaf, and can only have an analysis on leaves with specific curving characteristics.

C. Results of Model

N is the number of the leaves on the tree;

S is the area of a single leaf;

ρ is the surface density ;

M is the weight of leaves on the maple tree.

As for the maple used as an example, the number of the leaves simulated by computer belongs to $[2187\,,\,2357]$.

According to statistical data: the area of a single leaf is about 52cm^2, and the surface density is about 0.17g/cm^2.

Through calculation:

$$M = \rho \cdot S \cdot N \tag{8}$$

The weight of the leaves on the maple tree is 19.3kg to 20.8kg.

We have used the method of factor analysis for clustering of leaf shapes to reduce the number of variables and simplify our research workload. We use a few public factors to explain complicated relationships existing in more variables in observation. We use snowflake model to catch the law tree growth, well estimating the leaves quality of a tree. For the calculation the area of a single leaf, not only the comparatively flat leaves are considered, but also the calculation of the area of leaf surface when there is the problem of surface curving.

However because of time constraints, we couldn't find out large amount of data for verifying our theory.

V. CONCLUSION

Our main objective is about leaves quality research. First, we classify leaves based on different shapes, then simulate the processes of leaf growth and calculate total leaves per tree. According to the area and density of a leaf, we can easily estimate leaves weight of a tree.

In the process of leaf shape classification, we firstly analyze the diversification of leaf shape. From the genetic perspective, existing research data shows that long term environment impact changes the gene of tree and this is the most essential factor affected the shape of leaf. On the other hand, the open branch angle, DBH, knot spacing, crown diameter, clear length and tree height of tree will affect the shape of leaf. During the research, we found that the position of leaf also affects leaf shape. E.g., the smaller tip Angle will be the smaller leaf shape of the top branch. In the classification of leaf shape, if we directly classify leaf shapes according to the parameters of the leaf structure, it will be complicated. During analysis, we found the method that is using some indexes to classify leaf shape at first, and then classifying leaf forms again based on the structure of leaf. The method will reduce work load in the leaf shape classification, meanwhile, get a better result.

In the weight estimate of tree leaf, we divide into two steps. First step, we estimate the number of leaves. During research, we found and built the snow model theory that is high similarity between snow structure and tree structure (Therefore we get conclusion). The formation of the branch copies the exterior characteristics of the backbone. In the experimental simulation, simulated maple tree is highly similar with the actual sample at the aspects of crown diameter, breast diameter, number of branches, length and thickness of branches and so on. This suggests that the snow theory can be applied in the three growth simulation and it can be used in tree growth model in the future. Second step is estimating area of single leaf previous methods of the leaf area estimation are direct measurement method and mathematical model analysis. However, those methods cannot measure curvature leaves. We had the corresponding improvement. Firstly, we set up area measurement model to flat leaf. Then the area of the curly leaf was measured, which is dividing the whole curly leaf into small pieces. Finally, we calculate total area of all small pieces to get result. The measurement of the curly leaf has especially meaning because many factors in nature can influence of leaf form.

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