3D Forest-tree Modeling Approach Based on Loading Segment Models

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***Abstract*—For the difficulty of tree polymorphism 3D modeling in the forest stand, the paper explored a 3D forest-tree-modeling approach based on loading trunk model and branch models. The approach is fitted the crown curve with the basic tree measurement factors such as tree height, branch height, crown height and crown radius to define the initial crown shape, then combined with the characteristics of tree branch structure that calculate the branch matching points of the intersection between the branch model and the crown curve to construct the tree branch structure. In addition, branch models are adjusted to eliminate the overlapping of branch models when the adjacent trees had overlapping crowns. The 3D model of forest-tree was constructed in accordance with the growth law and morphological characteristics of forest-tree. The results showed that this approach can use a small amount of measurement data to simulate forest-tree crown of sample plot or stand.**

Keywords—3D forest-tree model, segment model, basic tree measurement factors, branch matching points, model overlap

I. INTRODUCTION

The 3D model of trees is an important part of the virtual reality environment, and it is also a difficult point in 3D visualization simulation. The diversity of the tree's own form and the complexity of the structure are important reasons for the difficulty of 3D modeling of trees [1]. As the tree in the stand environment, forest-tree are affected by adjacent trees and other forest environments during the growth process. The morphological structure of the forest-tree crown is quite different from isolated tree or marginal tree which has relatively regular crown. And it further increases the difficulty of three-dimensional simulation.

At present, many commonly used methods have been proposed in the field of 3D modeling of tree. Among them, common methods such as the L-system method proposed by Prusinkiewicz et al. to stipulate grammatical rules and iteratively obtain plant morphology according to the rules [2], and the improved L-system methods were proposed by many other researchers on this basis [3-5] , those methods improve the expression effect and operability of the L-system; For some tree structures with self-similarity, some researchers have proposed the IFS iterative function system method based on the fractal principle, which can simulate tree morphology by gradually iterating the self-similar parts [6]; With the development of computer graphics, an image-based tree modeling method has been proposed, which can reconstruct the tree model to restore the morphology of the tree by processing the real image of the tree [7]; Yang et al. considered space resource competition and proposed a 3D tree modeling method based on space resource competition algorithm[8], which improved the expression effect of the diversity simulation of tree morphology. These methods can build 3D model of tree quickly. With the development of virtual reality technology, many 3D modeling software and 3D rendering engines are used to construct and display 3D tree models, such as OSG rendering platform[9], OpenGL[10], SpeedTree[11], unity 3D rendering platform[12], all of these can realize the construction and rendering of the 3D model of tree.

In order to break through the existing research results which were closer to the three-dimensional simulation of the crown shape of isolated tree, this paper proposes to use basic tree measurement factors as the data to construct a segment models base, then according to the crown curve and branch structure characteristics, the segment models will be automatically loaded, and the cross-overlapping problem of adjacent tree's crown branches is considered. On this basis, the branching adjustment of the overlapping part is carried out to realize the expression and three-dimensional simulation of the irregular and large difference in the morphology and structure of the tree crown due to the incomplete shape of the tree crown caused by the environmental impact. At the same time, the 3D model of the forest- tree constructed by loading the segment models is convenient to simulate the natural pruning of branches and adjust the branch distribution. Compared with most overall modeling methods, the 3D model constructed by this method is more flexible.

II. MATERIALS AND METHODS

A. Research Data

In this study, Chinese fir was selected as the research object, and a 20meters×20meters plantation plot containing 56 Chinese fir trees in the Shanxia Forest Farm of the Experimental Center of Subtropical Forestry of Fenyi County, Jiangxi Province was selected as the research area. Chinese fir is widely cultivated in China's Yangtze River Basin and the area south of the Qinling Mountains. As a fast-growing tree species, its main values have the ecological value as a street tree and building windbreaks; economic value for construction, shipbuilding, bridges, furniture construction, etc.; and has a certain medicinal value. As a coniferous tree species, the trunk of Chinese fir is straight, and when the competition is small, the crown shape is relatively complete and presents a tower or conical shape. The branches are mainly whorls. The leaves are arranged approximately symmetrically on the branches and branches. Its morphological structure relatively regular and simple, it reduces the difficulty in the process of 3D modeling of trees, so it's facilitate the study of 3D forest-tree model's construct. In this study, the RTK was used to measure the relative positions of 56 Chinese firs in the study area to obtain (X, Y, Z) relative position coordinates. At the same time, the basic tree measurement factors were measured for each tree in the sample plot, then the diameter of breast height (DBH), tree height(H), under-branch height (Hb), crown height (Hc), and crown radius (Cr) of each tree in the east, west, south and north directions were obtained. . Without considering the relative height, the relative position (X, Y) of the Chinese fir in the horizontal direction within the plot is shown in Figure 1.

B. Build Crown Curve

The most intuitive manifestation of the diversity of tree morphology lies in the diversity of the crown morphology, and the crown of each tree will show differences in the growth process, but the crown morphology of trees of the same tree species will have certain similarities and correlations. For the crown morphology of coniferous trees, the research is mostly expressed by the crown curve [13、14]. When as the isolated tree or marginal tree which is less affected by the competition of adjacent trees and the environment, the crown can maintain a

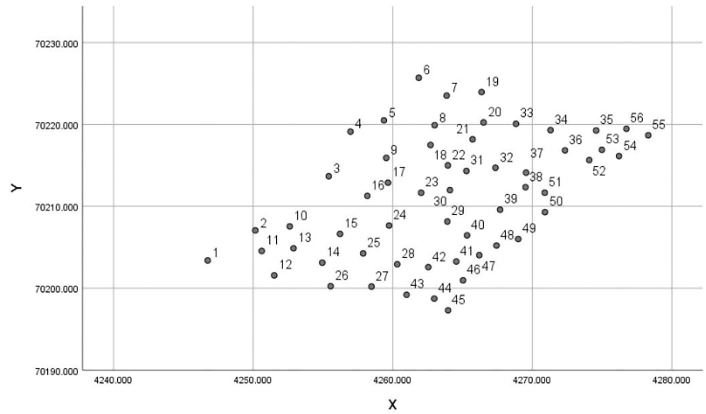


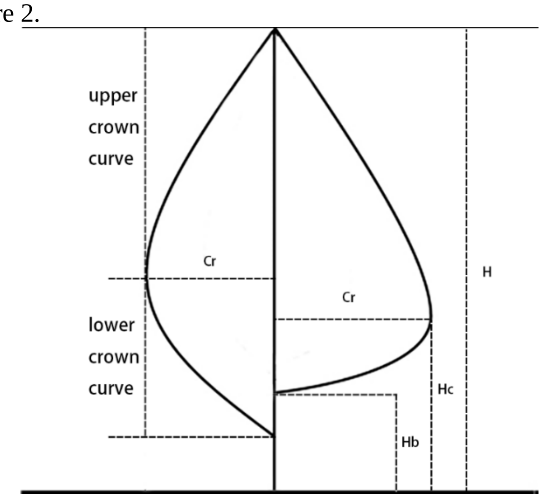
Fig.1. Relative position of trees

relatively complete shape, and the constructed crown curve can more accurately express the crown shape and conveniently control the branch distribution. The crown shape of different trees can be simulated by adjusting the measurement parameters of trees. Because of the different trends of crown shapes above and below the crown height, the crown curve in each direction is divided into two parts, the upper crown curve and the lower crown curve, with the crown height as the dividing line. Using measured data such as tree height, crown height, under-branch height, crown radius in each direction from east to west, north and south, as parameters, fit the upper and lower crown curve in each direction, the expression is:

$$\begin{cases} h_{up}=H-[(H-H_c)x^{\alpha_1}/C_r^{\alpha_1}] \\ h_{down}=H_b+[(H_c-H_b)x^{\alpha_2}/C_r^{\alpha_2}] \end{cases} \tag{1}$$

Where h_{up} represents the height corresponding to the crown radius x above crown height of the constructed crown curve; h_{down} represents the height corresponding to the crown radius x below the crown height of the constructed crown curve; H represents the height of the tree; H_c represents the height of the crown; H_b represents the under-branch height; α1, α2 represent the crown index; C_r represents the crown radii in all directions.

By substituting the relevant measurement data into the crown curve expression, the parameters can be solved to obtain the crown contour line of each direction of the tree, as shown in Figure 2.



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C. Construct Segment Models

The composition structure of Chinese fir can be decomposed into the trunk, the first-level branches, second-level branches, leaves and so on. The crown morphology will directly affect the tree morphology, and the morphological structure of first-level branches and the position distribution on the trunk are the direct factors that affect the crown morphology. At the same time, considering the amount of calculation of the subsequent loading model, this study dissects the Chinese fir model as a trunk model and first-level branches model.

The theoretical basis of the trunk model and the first-level branches model are the trunk taper equation and the morphological and structural characteristics of first-level branches respectively. The theoretical basis for the construction of the trunk model is the Chinese fir taper equation proposed by Zeng et al. [15], it can be used to describe the outline of the trunk. The equation expression is:

$$\begin{cases} d/D = [(H-h)/(H-1.3)]^{C_0+C_1 z^{1/4}+C_2 z^{1/2}+C_3(D/H)} \\ z = h/H \end{cases} \quad (2)$$

Where H represents the height of the tree; D represents the diameter at breast height; h represents the height of a certain position of the trunk; and d represents the diameter of the corresponding trunk at that height. In this paper, the parameters C_0, C_1, C_2, and C_3 are 3.99786, -8.63324, 5.11564, and 0.19384, respectively.

And the theoretical basis for the construction of first-level branch model is the morphological and structural characteristics of first-level branch. Because the overall morphological structure of Chinese fir conforms to the fractal theory and has self-similarity, the morphological structure of first-level branches is similar to the overall morphological structure of the tree. The distribution characteristics of the second-level branches are the basis of the first-level branches. Chinese fir's elevation angle of the second-level branches basically conforms to the normal distribution, it mainly concentrated in the range of 50°~100°, and the azimuth angle is mainly concentrated in the interval of 135°~225° and 315°~45°, distributed in the horizontal direction. The leaves are arranged approximately symmetrically on the branches [16-18].

SpeedTree is currently a more professional and complete tree 3D modeling software. In this study, the software is used to assume that the forest-tree morphology is straight and full, at the same time without considering the bending or broken tips of the trunk, the trunk model of the Chinese fir is constructed based on the taper equation to limit the trunk's morphology, and add the bark texture to the model. According to the theoretical basis of the construction of the first-level branches, the leaf layout is constructed as the second-level branching model in the reduced trunk model, which adjusts the position distribution of the second-level branches and constructs multiple first-level branches. The bark texture used in the construction of the trunk and first-level branches is shown in Figure 3, and the leaf texture is shown in Figure 4.

Fig.2. The texture of bark

Fig.3. The texture of leaf

D. Branch Matching Points

The branch matching point is the intersection point between the first-level branch model and the crown curve. The branch point is the position where the first-level branch grows on the trunk. In the process of building the forest-tree model, the corresponding branch point and branch matching point determine the branch distribution and length. The construction of branch matching points requires the use of the distribution characteristics of first-level branches in the trunk. The branch growth of Chinese fir belongs to whorls. It grows one round of branches every 5cm, and grows 3 to 5 rounds a year; the azimuth angles of the first-level branches are nearly evenly distributed in four directions; the branch elevation angles of the first-level branches are distributed in 30° ~ 90°, the elevation angle from the lowest point to the highest point shows a decreasing trend, and most of them are concentrated between 70° ~ 80°. Therefore, the branch elevation angle distribution divides the crown length into 3 layers, the upper, middle and lower layers, and the probability of the elevation angle of each layer conforms to the normal distribution. The elevation angle of the lower first-level branches is set to 70°~90°, the middle layer is 50°~70°, and the upper layer is 30°~50°. The expression is as follows:

$$\text{Branch\_Elevation} = \begin{cases} \text{Normal}(70°,90°) \\ \text{Normal}(50°,70°) \\ \text{Normal}(30°,50°) \end{cases} \quad (3)$$

Where Branch_Elevation is the branch elevation angle of the first-level branch; Normal(min°,max°) is an angle obtained randomly from the min~max interval, and the probability of occurrence of this angle obeys the normal distribution of the interval.

A ray is made from the branch point along the given azimuth angle and branch elevation angle, and the intersection point with the crown curve is the branch matching point. The branch length is calculated through two points, and the length of each branch model is determined before the branch model is loaded. The calculation formula is:

$$\begin{cases} \text{Branch\_Length}= x/\sin\theta \\ \text{Branch\_Height}+ x/\tan\theta = f(x) \end{cases} \quad (4)$$

Where Branch_Length represents the branch length, x represents the crown radius in the extension direction of the branch, θ represents the branch elevation angle, Branch_Height represents the branch height, and f(x) represents the crown curve equation in this direction.

During the growth process of Chinese fir, branches will die naturally, so the first-level branch number model of Chinese fir was fitted [15], assuming that the branches gradually fall off from the bottom upwards, passing through the average number of branches per round，calculate the number of fall off branches.

$$\begin{cases} y_1=-1.06*x^2+27.63x-38.33 \\ y_2=1.0553*x^2-9.2039x+35.012 \end{cases} \quad (5)$$

Where y1 is the number of first-level branches; y2 is the number of dead branches; x is the age of Chinese fir.

This model is used to adjust the number of branches in the initial state to optimize the distribution of branch matching points.

E. Judgment of Crown Overlap

The judgment of the overlap of adjacent tree crowns is mainly divided into two parts: 1. Determine whether there is a phenomenon of overlap of tree crowns; 2. Determine the type of overlap of tree crowns.

The first part: whether the crowns of adjacent trees are overlapped or not is judged by the relative distance between the crown radius of two trees in the adjacent direction and the horizontal direction of two trees. The crown radius is the longest part of the tree crown. By summing the crown radius (C_r) of two trees in the adjacent direction, the result l_c can be obtained:

$$l_c=C_{r1}+C_{r2} \quad (6)$$

For two adjacent trees with coordinates (X1, Y1, Z1) and (X2, Y2, Z2), the horizontal relative distance l_p between (X1, Y1) and (X2, Y2) is calculated without considering the relative height. The calculation formula is:

$$l_p=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2} \quad (7)$$

When $l_p<l_c$, the sum of the lengths of the longest branches of adjacent trees is longer than the relative distance between two trees, so adjacent trees have overlapping crowns. Conversely, when the relative distance is longer than the sum of crown radius, there is no overlap of the crown.

If the result of first part is exist the situation of overlap, according to the characteristics of the crown shape of conifers and the intersection of the common crown shape curves of adjacent trees in the forest, there are two types: the upper and lower crown curves of adjacent trees intersect respectively (as shown in Figure 5a), and the upper and lower crown curves of one tree intersect with the upper crown curves of another tree (as shown in Figure 5b).

The intersection of adjacent wood crown curves can be solved in these two cases:

(a) When the upper and lower crown curves of tree 1 and tree 2 intersect respectively, the heights of the intersection points h_up and h_down can be obtained according to the following formula:

$$\begin{cases} \text{f1\_up}(x1)=\text{f2\_up}(dis-x1) \\ \text{h\_up}=\text{f1\_up}(x1) \\ \text{f1\_down}(x2)=\text{f2\_down}(dis-x2) \\ \text{h\_down}= \text{f1\_down}(x2) \end{cases} \quad (8)$$

Where f1_up(x1) is the upper crown curve equation of tree 1; x1 is the horizontal distance between the intersection point of the upper crown and tree 1; f2_up(dis-x1) is the upper crown curve equation of tree 2; dis is the distance between tree 1 and tree 2; f1_down(x2) is the lower crown curve of tree 1; x2 is the horizontal distance between the intersection point of the lower crown and tree 1; f2_down(dis-x2) is the lower crown curve equation of tree 2.

(b)When the upper crown curve of tree 1 intersects the upper and lower crown curves of tree 2, the heights h_up and h_down of the intersection points can be obtained according to the following formula.

$$\begin{cases} \text{f1\_up}(x1)=\text{f2\_up}(dis-x1) \\ \text{h\_up}=\text{f1\_up}(x1) \\ \text{f1\_up}(x2)=\text{f2\_down}(dis-x2) \\ \text{h\_down}= \text{f1\_up}(x2) \end{cases} \quad (9)$$

Where f1_up(x1) is the upper crown curve equation of tree 1; x1 is the horizontal distance between the intersection point of the upper crown and tree 1; f2_up(dis-x1) is the upper crown curve equation of tree 2; dis is the distance between tree 1 and tree 2; x2 is the horizontal distance between the intersection point of the lower crown curve and tree 1; f2_down(dis-x2) is the lower crown curve equation of tree 2.

F. Segment model loading to eliminate crown overlap

At first, load the segment models according to the survey data and related models to obtain the initial 3D model of the forest-tree. Determine the position of the tree by the relative position coordinates (X, Y, Z) of the single tree, and determine

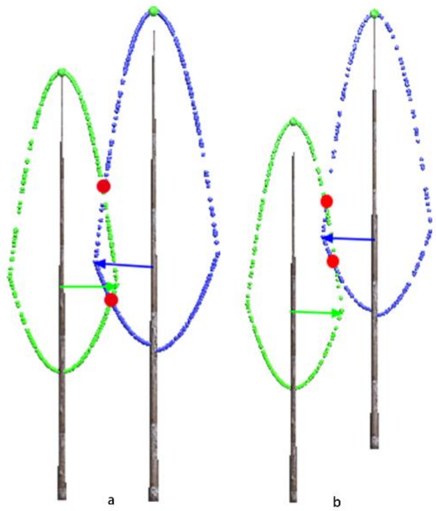

Fig.4. Schematic diagram of crown overlap

the matching point of the trunk root Trunk_RootPos and the vertex Trunk_TopPos through the tree height data, so as to adjust the size and position of the trunk model constructed. The formula for trunk matching point is:

$$\begin{cases} \text{Trunk\_RootPos} = (x,y,z) \\ \text{Trunk\_TopPos} = (x,y+h,z) \end{cases} \quad (10)$$

On the trunk model, the branch models are loading limited of branch matching points. the branch point Branch_RootPos,the branch top point Branch_TopPos related to each branch matching point and assuming the branch length Branch_Length, the horizontal projection Branch_LenV and the vertical projection Branch_LenH are calculated as follows:

$$\text{Branch\_RootPos} = (x, y+\text{Branch\_Height}, z) \quad (11)$$

$$\text{Branch\_LenV} = \text{Branch\_Length} * \sin\theta \quad (12)$$

$$\text{Branch\_LenH} = \text{Branch\_Length} * \cos\theta \quad (13)$$

$$\text{Branch\_TopPos} = \text{Branch\_RootPos} + \begin{cases} (\text{Branch\_LenV}, \text{Branch\_LenH}, 0) \\ (-\text{Branch\_LenV}, \text{Branch\_LenH}, 0) \\ (0, \text{Branch\_LenH}, \text{Branch\_LenV}) \\ (0, \text{Branch\_LenH}, -\text{Branch\_LenV}) \end{cases} \quad (14)$$

In this way, load the adjusted size branch models in the corresponding position, and complete the construction of the initial 3D forest-tree model.

After constructing the initial 3D forest-tree model, it need to judge whether there is overlap between adjacent tree crowns. If this situation exists, this paper will calculate the space competition ratio between adjacent trees, and alternately delete the branches of the overlapping parts of the two trees based on this situation. Then to eliminate the overlap of the crown models of the two trees.

Forest-tree space competition can be divided into vertical and horizontal competition. The horizontal competition ratio (C_h) can be expressed by the crowns length ratio, the vertical competition ratio (C_v) can be expressed by the relative height ratio, The horizontal competition ratio and the vertical competition ratio are expressed as:

$$\begin{cases} C_h = C_{r1} / C_{r2} \\ C_v = (H_1 + Z_1) / (H_2 + Z_2) \end{cases} \quad (15)$$

Combining horizontal competition and vertical competition, the proportion space competition (C_t) of adjacent trees is obtained according to their respective 50% influence rate:

$$C_t = 0.5 * C_h + 0.5 * C_v \quad (16)$$

The overlapping branches are deleted one by one according to the spatial competition ratio of two trees to eliminate the overlap of the crown caused by the intersection of branches, simulating the natural pruning situation of the forest.

In order to ensure that the 3D model conforms to the real measurement data when there is crown radius overlap, the branch elevation and azimuth angles of the crown radius of the tree with a small spatial competition ratio are adjusted to eliminate the crown radius crossing situation.

III. PROCESS AND RESULTS

The construction of the 3D forest-tree model based on the segment model loading can be realized step by step. It is possible to separately simulate two situations where there is no overlap of crowns and the existence of overlap of crowns.

A. *Segment Models*

According to the measurement data and the bark texture, Taking the data of 15 cm diameter at breast height and 12 meters of tree height as an example, starting from the root of 0 meter, the trunk diameter of the corresponding height is obtained every 0.2 meters, constructed trunk model is shown in Figure 6.

For the construction of branch model, start from 30°, set a branch elevation angle every 10°, until 90°, a total of 7 branch elevation angles; and start from 0.4 meters, set a branch length every 0.4 meters, until 3.2 meters , A total of 8 first-level branch lengths, build the branch model within the initial range. Taking the first-level branch, the branch elevation angle of 70° and branch length of 2 meters as an example, the3D model of the branch is constructed as shown in Figure 7.

H/m	D/m
0.0	0.2439
0.5	0.1657
1.0	0.1545
1.5	0.1474
2.0	0.1419
2.5	0.1373
3.0	0.1330
3.5	0.1289
4.0	0.1247
4.5	0.1204
5.0	0.1159
5.5	0.1112
6.0	0.1061
6.5	0.1007
7.0	0.0948
7.5	0.0885
8.0	0.8181
8.5	0.0745
9.0	0.6678
9.5	0.0584
10.0	0.0494
10.5	0.0397
11.0	0.0291
11.5	0.0172
12.0	0.0000

Fig.5. Trunk model

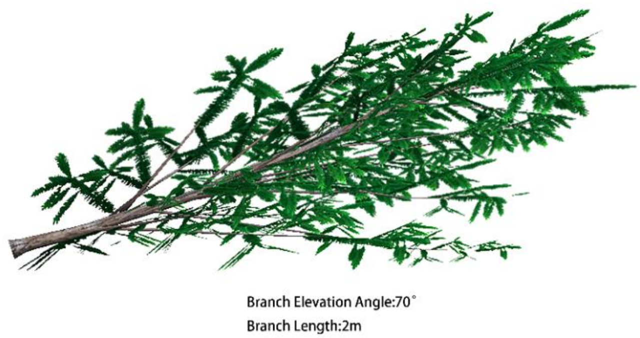

Fig.6. The first-level branch model

B. 3D Forest-tree Model without Overlapping Crown

The number 1 Chinese fir in the sample plot has no adjacent tree in the Y direction, and the nearest adjacent tree in the X direction is the number 11 Chinese fir. The crown on the east side of Chinese fir 1 is adjacent to the crown on the west side of Chinese fir 11. The horizontal coordinates and adjacent crown radii of two trees are shown in Table 1.

After calculation, the relative distance between two trees is 4.04m, and the sum of the crown radii in the adjacent direction of two trees is 4m. The relative distance is longer than the length of the crown radii, and there is no overlap of the crown. According to the tree 1 measurement data modeling, the tree 1 measurement data is shown in Table 2.

The value range of the crown index α of Chinese fir is (1≤α≤2). According to the measurement data, the crown curve of the tree in the four directions can be calculated as:

$$\text{East crown curve} \quad \begin{cases} h_{up}=20.2\text{-}2.59x^2 \\ h_{down}=5.8+0.68x^2 \end{cases} \tag{17}$$

$$\text{West crown curve} \quad \begin{cases} h_{up}=20.2\text{-}1.82x^2 \\ h_{down}=5.8+0.48x^2 \end{cases} \tag{18}$$

$$\text{South crown curve} \quad \begin{cases} h_{up}=20.2\text{-}5.07x^2 \\ h_{down}=5.8+1.33x^2 \end{cases} \tag{19}$$

$$\text{North crown curve} \quad \begin{cases} h_{up}=20.2\text{-}1.98x^2 \\ h_{down}=5.8+0.52x^2 \end{cases} \tag{20}$$

According to the definition of the crown curve in each direction and the loading method based on Chinese fir morphology and structure of the segment models, the trunk matching points and the branch matching points in the four directions of the tree 1 can be obtained, as shown in Figure 8.

TABLE I. TREE 1, TREE 11 POSITION AND CROWN RADIUS DATA

Number	X coordinate (m)	Y coordinate (m)	Crown radius(m)
1	4246.742	70203.39	2.1(E)
11	4250.612	70204.545	1.9(W)

TABLE II. TREE 1 MEASUREMENT DATA

DBH (cm)	H (m)	H_c (m)	H_b (m)	C_r(m)			
				East	*West*	*South*	*North*
28.1	20.2	8.8	5.8	2.1	2.5	1.5	2.4

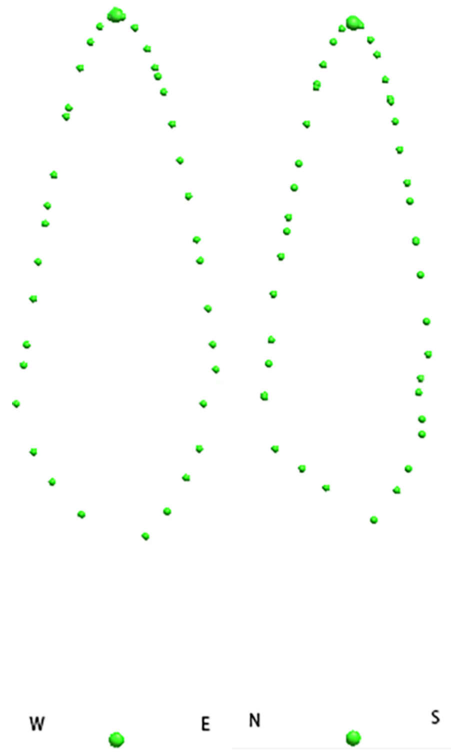

Fig.7. Trunk matching points and branch matching points of Chinese fir 1

Load the 3D trunk model and 3D branch models on this basis to construct the 3D model of Chinese fir 1, as shown in Figure 9.

Fig.8. 3D model of Chinese fir 1

C. 3D Forest-tree Model with Overlapping Crown

The south side of number 10 Chinese fir in the sample plot is adjacent to the north side of number 13 Chinese fir. The relative position coordinates of the two trees and the crown radii of the adjacent direction are shown in Table 3.

After calculation, the relative distance between two trees is 2.69m, and the sum of the crown radii in the adjacent direction of the two trees is 3.4m. The crown radii are longer than the relative distance, so there is overlap between the crowns. According to the measurement data, the crown curve on the south side of tree 10 and the crown curve on the north side of tree 13 are constructed. The measurement data of the two trees are shown in Table 4. In this paper, for the convenience of calculation, the crown index is selected as 2.

The south crown curve of tree 10 is:

$$\begin{cases} h_{up}=19.1-1.8x^2 \\ h_{down}=8+2.1x^2 \end{cases} \quad (21)$$

The north crown curve of tree 13 is:

$$\begin{cases} h_{up}=21-2.2x^2 \\ h_{down}=5.2+3.2x^2 \end{cases} \quad (22)$$

The crown curves and intersections of two trees in the adjacent direction are shown in Figure 10.

It can be seen from Figure 10 that the two trees conform to the upper and lower crown curves respectively intersecting, so the height h_up of the upper crown curve of the intersection is calculated to be 16.33m, and the height h_down of the lower crown curve is 11.49m. The green dot marks the branch matching point between the upper and lower intersection points of the two trees. The red dot marks the branch matching point where the crown radius is recorded. The spatial competition ratio is calculated by the tree height, relative height of position and crown length data. The spatial competition ratio Ct between tree 10 and tree 13 is 0.94, so the branch adjustment is close to the 1:1 ratio reduction branch model, and because the space competition of tree 13 is relatively large, keep the branches where the crown radius is located, adjust the azimuth and elevation angles of the branches where the crown radius of the tree 10 is located. That the elimination of the crown cross overlap is simulated. The 3D models of adjacent trees: Chinese fir 10 and Chinese fir 13 constructed by this method is shown in Figure 11. As a contrast, the traditional IFS iterated function system is used to build tree 10 and tree 13 3D models, as shown in Figure 12.

TABLE III. TREE 10, TREE 13 POSITION AND CROWN RADIUS DATA

Number	X coordinate (m)	Y coordinate (m)	Z coordinate (m)	Crown radius(m)
10	4252.617	70207.551	-4.304	1.7(S)
13	4252.891	70204.877	-3.589	1.7(N)

TABLE IV. TREE 10, TREE 13 MEASUREMENT DATA

Number	DBH (cm)	H (m)	H_c (m)	H_b (m)	C_r(m) East	West	South	North
10	24	19.1	14	8	1.6	1.2	1.7	1.4
13	25	21	14.5	5.2	1.4	1.9	2.8	1.7

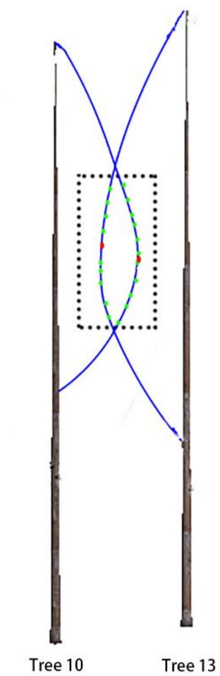

Fig.9. Crown curve diagram of adjacent direction of tree 10 and tree 13

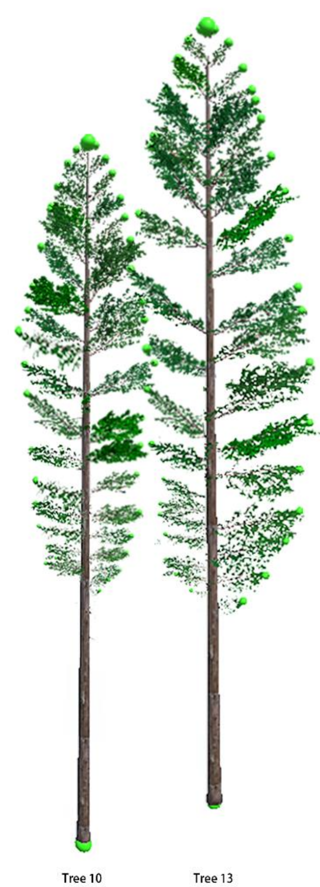

Fig.10. Crown overlapped of 3D models of tree 10 and tree 13

Fig.11. 3D models of tree constructed based on IFS iterative function system

IV. CONCLUSION AND DISCUSSION

Compared with the existing methods, the 3D forest-tree modeling approach based on loading segment models has the following advantages:

1) Based on the measurement data of forest-tree, this paper loads the trunk and branch models by the limits of the crown curve to ensure the reducibility of the constructed model for the morphological and structural characteristics of the forest-tree. At the same time, the construct method of loading segment models makes the modeling process more flexible. For the construction of different forest-tree models, that only need adjust the size and distribution angle of the first-level branch model by the limit of the corresponding crown curve. In addition, loading segment models can facilitate the simulation of the natural pruning of the branches on the forest-tree, and can effectively simulate the fall of the branches and the change of the branch elevation angle with the growth when simulating the growth of forest-tree. When the precise simulation of large-scale forest-trees is not required, it can be realized by adjusting the trunk model and branch models randomly. This method is more flexible than existing methods in static 3D forest-tree modeling and application in dynamic growth simulation. It is suitable for the simulation of forest-tree diversity and changes.

2) Different from the existing 3D modeling methods for trees, the results of the models constructed by the existing methods are closer to the simulation of isolated tree. Although the simulation of morphological diversity can also be realized by adjusting the corresponding parameters, it can not effectively simulate the incomplete and irregular crown morphology caused by natural pruning and elevation change during the growth process. The original intention of this method research is to simulate the trees in the stand environment. The research is to consider the environment and the influence of adjacent trees to cause the diversification and differentiation of forest-tree morphology. By adjusting the distribution of branch models, the diversity of tree crown morphology is shown. Therefore, the simulation results avoid the situation that the crown morphology of the constructed model is complete, symmetrical and regular to a certain extent. It has certain advantages in 3D visualization simulation to directly express the characteristics of forest-tree measurement data and express the morphological characteristics of the trees in the stand.

3) Compared with the existing methods, this method not only considers the morphological and structural characteristics of the trees themselves obtained through the measurement data, but also considers the impact of competition between adjacent trees when constructing the 3D forest-tree model. In the stand space, the branches growing between trees with relatively small distances may be to reach the crown of adjacent trees. The simulation results of existing methods usually ignore this phenomenon. As shown in Figure 12, the tree 10 and tree 13 have partial overlaps in the crowns. The simulation results do not make any treatment for this situation so that the crown models simply overlap each other, which is quite different from the real tree morphology and structure characteristics. Based on the loading of the segment models, this method takes into account the overlap of tree crowns, according to the spatial competition ratio, the natural pruning of the forest-tree is simulated, and the branches of the overlapping part are adjusted, so that the simulation result is closer to the distribution of the branches of the trees in the stand. To a certain extent, the accuracy of 3D forest-tree simulation has been improved.

Of course, there are still some shortcomings in this method, which can be further improved in future research:

In the process of realizing this method to construct the 3D forest-tree model, a large number of researches on the morphological and structural characteristics of trees are needed as the theoretical support of the early stage. At the same time, considering that the spatial competition ratio is the mutual influence relationship between forest-trees, in further research, more measurement data can be collected to fit more accurate spatial competition relationships, and achieve the adjust of crown overlap that is more in line with the laws of forestry.

By comparing the results of constructing adjacent trees with this method in Figure 11 and the results of constructing adjacent trees based on the IFS iterative function system in Figure 12, it can be seen that although this method is more realistic for the simulation of forest-tree morphology and structure, it is closer to the real forest. However, this method is still lacking in aesthetics. The 3D visualization research of trees not only pursues authenticity, but also needs to consider the aesthetics of the model under the premise of ensuring true restoration. This is also a point that needs to be improved in subsequent research.

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