Research Article

Hedera Nepalensis Cutting Propagation Based on Fractal Theory for Promoting Green Environment

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The green environment is the need of the hour. There are many techniques opted by the agriculture experts for Hedera nepalensis cutting propagation. In order to simulate the propagation pattern of Hedera nepalensis cuttings more vividly, the simulation method of Hedera nepalensis cuttings propagation based on fractal theory has been studied in this paper for promoting green environment. The rule of L-system to generate to Hedera nepalensis graphics is elaborated in detail. The composition of generators is represented by strings, and Hedera epalensis fractal images are generated repeatedly by recursive algorithm. Combining BSP technology (Binary Space Partitioning Tree) with L-system, the simulation model of Hedera nepalensis cutting propagation is designed. The mechanism and morphological difference of real Hedera nepalensis cutting propagation are investigated in detail. The different Hedera nepalensis organs are distinguished by static simulation and the mathematical model is established. With the help of GDI+, random functions are flexibly used in programming control to simulate the process of Hedera nepalensis cutting propagation. By determining the growth proportion coefficient of each organ and the growth coefficient of control parameters, the image of Hedera nepalensis cutting reproduction is generated continuously from the dynamic control parameters and the dynamic process of Hedera nepalensis cutting reproduction is simulated. The simulation results show that the simulation error of this method is less than 0.8%. The simulation process is simple and efficient, and the simulation results are vivid and viable to suggest newer solution for Hedera nepalensis cutting propagation to protect the environment.

1. Introduction

1.1. Background Study. Hedera nepalensis, also known as Ivy, Soil Drum, and Centipede, is well-known for its adaptability to the environment, resistance to humidity, drought and barrenness, smoke, dust, reducing sunlight reflection and lowering temperature [1, 2]. There are many varieties of mosaic Hedera nepalensis. There are two common species, i.e., large-leaved and small-leaved, originating in Europe and Japan, respectively. There are mainly two subspecies of Hedera nepalensis

1.1.1. Hedera Nepalensis Var. Nepalensis

(1). It is characterized by triangular-ovate to ovate-lanceolate triangular leaves. Leaves are taper-pointed.

(2). Length is 2 to 41⁄2 inches and width is 1 to 21⁄2 inches.

(3). It has two blunt lobes near the base with blunt teeth on the upper part of the leaf.

(4). Fruits are yellow or orange in color.

(5). The young stems, petioles, and inflorescence parts are scaly, the scales yellowish brown, twelve- to fifteen-rayed.

1.1.2. Hedera Nepalensis Var. Sinensis (Tobler) Rehder

(1). It is found in China.

(2). It has juvenile leaves entire or three-lobed near the base and hence lacking the lobules in the upper part of the leaf.
Hedera nepalensis is distributed in central China, southern China, southwest China, Gansu, and southern Shaanxi, as well as in the continental areas south of Henan and Shandong provinces; Fanjingshan, Yinjiang, Jiangkou, Shibing, Xishui, Zunyi, Dejiang, Anlong, Ceheng, Congjiang, Guiding, and Libo are also distributed in counties and cities in Guizhou, and they are often found in forests with altitudes of 530–2300 m. Hedera nepalensis likes relatively cold climate, cold resistance is strong, belongs to evergreen climbing vine, slightly spiral growth of vines, stems and branches full of air rooting, and with glue-like mucus, can firmly adhere to walls or other objects. The stem of Hedera nepalensis can reach more than 20 m. It has epiphytic roots and scales on its tender branches. Leaves are alternate, leathery, and dark green, with long petioles, leaves on vegetative branches are triangular ovate, and leaves on flower branches ovate to rhombic. The stem of Hedera nepalensis contains tannin and resin, which can extract baking gum. Hedera nepalensis can be propagated by means of ramification and cuttage [4], mainly by young cuttings, which can be carried out indoors or in greenhouses for 3–4 months. Cutting can be carried out in water, sand, vermiculite and perlite, slag, peat, and other substrates [5]. The suitable cutting medium has good ventilation conditions, does not contain organic fertilizer and other easily mildewed impurities, and maintains certain humidity. Hedera nepalensis leaves contain hederin, inositol, carotene, etc. The whole plant has good therapeutic effect on rheumatic arthritis, rheumatic arthralgia, fracture, wind-cold cough, edema, hepatitis, dizziness, anemia, gangrene, swelling and pain, and chronic spleen wind in children. Therefore, it is one of the commonly used Chinese herbal medicines and can effectively resist the carcinogenic substances in nicotine [6, 7]. Hedera nepalensis leaves have fragrance and a beautiful shape. In the same plant, the leaves have various shapes. The leaves have beautiful silver-white patterns; racemes’ small flowers are spherical and light yellow. Some leaves gradually turn red after autumn. The whole plant is red and green, which is very spectacular. The flowers are fragrant, the stone fruit is spherical, which matures in April to May of next year, and the fruit is red when it ripens. Hedera nepalensis propagation experiment is rarely reported, so Hedera nepalensis cuttage propagation has important research significance. In [8], authors have mentioned medicinal importance of Hedera nepalensis within local Pakistani traditions. Their data shows that H. Nepalisn harbors cancer chemo preventive and cytotoxic agents. Considering its significance in medicines, its propagation should be studied in order to increase its production.

1.2. Literature Review. In [9], the authors mention that, fractal theory is a new subject developed in the past two or three decades. It mainly describes the unsmooth and irregular geometric shapes in nature and nonlinear systems. In [10], the authors propose that, the fractal can be divided into regular fractal and irregular fractal: regular fractal graphics have strict self-similarity, such as Cantor set, Koch curve, Sierpinski gasket, carpet, and sponge. Irregular fractals are characterized by irregularity of morphology, fineness of structure, self-similarity between local and global, non-integer dimension, and iteration of generation. The self-similarity of these curves is limited to a certain scale range, but no longer exists beyond the scale area, such as winding coastlines, changing infinite Brownian motion, and beautiful and colorful coral. This kind of graphics cannot be described by classical Euclidean geometry, nor can it be represented by traditional drawing methods. The coupling of its artistic form can be generated by computer simulation, so the application of fractal graphics is more and more extensive. In [11], authors propose that though there are many kinds and shapes of plants in nature, most of them have the fractal characteristics of self-similarity and self-reproduction. In recent years, with the research and development of fractal science, plant simulation has become a hot topic. Plant simulation plays an important role in artificial intelligence, computer games, virtual reality, teaching software, agricultural and forestry research and other fields [12], and has broad application prospects. Therefore, the simulation method of Hedera nepalensis cuttage propagation based on fractal theory is studied, and the process of Hedera nepalensis cuttage propagation is simulated by fractal theory, which provides a theoretical reference for Hedera nepalensis cuttage propagation. In [8], authors have mentioned medicinal importance of Hedera nepalensis within local Pakistani traditions. Their data shows that H. nepalensis harbors cancer chemo preventive and cytotoxic agents. In [13], authors have used L-System method for predicting the possible shape of a plant stem using its iterative writing rules based on the original object photo. In [14], authors mention that the applications involving 3D geometric models and generating images of objects are crucial operations.

These operations require the mapping of spatial relations between objects. As the objects are made of many pieces, computation of spatial relations between n polygons become complex. This complexity can be reduced using binary space partitioning trees.

1.3. Contribution of the Paper. The major contributions of the manuscript are as given below:

(i) The simulation method of Hedera nepalensis cuttings propagation based on fractal theory has been
studied in this paper for promoting green environment.

(ii) The rule of L-system to generate to Hedera nepalensis graphics is elaborated in detail. The composition of generators is represented by strings, and Hedera nepalensis fractal images are generated repeatedly by recursive algorithm.

(iii) Combining BSP technology (binary space partitioning tree) with L-system, the simulation model of Hedera nepalensis cuttage propagation is designed.

(iv) The mechanism and morphological difference of real Hedera nepalensis cuttage propagation are investigated in detail. The different Hedera nepalensis organs are distinguished by static simulation and the mathematical model is established. With the help of GDI+, random functions are flexibly used in programming control to simulate the process of Hedera nepalensis cuttage propagation.

(v) By determining the growth proportion coefficient of each organ and the growth coefficient of control parameters, the image of Hedera nepalensis cuttage reproduction is generated continuously from the dynamic control parameters and the dynamic process of Hedera nepalensis cuttage reproduction is simulated.

(vi) The simulation results show that the simulation error of this method is less than 0.8%. The simulation process is simple and efficient, and the simulation results are vivid and viable to suggest newer solution for Hedera nepalensis cuttage propagation to protect the environment.

The next section discusses about the methods and materials used for the research study, followed by the results of the work and then the research study is concluded.

2. Materials, Simulation Tool, and Methods

Hedera nepalensis cuttage propagation simulation based on fractal theory is the morphological simulation of Hedera nepalensis based on fractal theory. Its principle is to use the fractal nature of Hedera nepalensis structure (structural self-similarity) to generate plant graphics or images.

2.1. Simulation Tool. Matlab with fractal analysis package has been used for simulation purpose. It provides the set of functions to analyse the geometry of particle aggregates in black and white binary images.

The various functions in the package determine several geometric aspects of the connected components of the image (i.e., the clusters), such as average cluster area, centre of mass coordinates for each cluster, the gyration radius of each cluster, and the correlation length of the image.

2.2. Basic Principles of L-System. L-system was designed by American biologist A. Lindenmayer in 1968 to simulate biological morphology. It focuses on the description of plant morphology and growth. It describes the topological structure of plants by generating sequence of characters, construction axioms, and generation rules [15], i.e., between the main trunk and the side branches of plants. Neighbouring relations were later added to the description process to form the so-called L-system. In 1984, A. R. Smith first combined L-system with computer graphics, providing a powerful tool for computer simulation of plant growth. L-system is actually a repetitive replacement system [16]. It uses the strings defined by the generating rules to replace each character of the previous level repeatedly. It is a simple and quick method of drawing fractal graphics by computer, but it can draw complex and beautiful graphics. Therefore, using L-system to simulate Hedera nepalensis cuttage propagation has the characteristics of simple definition, high degree of structure, strong graphics compression ability, and easy realization. Its theoretical basis is mainly based on the basic principle that fractal can be generated by iteration of generators. Therefore, the composition of generators can be represented by strings, and the desired fractal image can be generated by iteration of strings repeatedly.

Take deterministic L-system (usually referred to as DOL system) as an example, let $V$ denote the alphabet and $V'$ denote the set of all words on $V$, a deterministic L-system is an ordered triple $V/G = (V, \omega, P)$, where $\omega$ is a nonempty word, called axiom; $P$ is a finite set of production. The initial object (also known as axiom) in L-system, i.e., Hedera nepalensis twigs and production rules are described by strings [17]. Its mathematical model can be explained by the “tortoise walking algorithm.” The tortoise shape is defined as a set of three elements $(x, y, a)$, in which the Cartesian coordinate $(x, y)$ represents the position of the tortoise shape; the direction angle $a$ represents the direction of the tortoise head, gives the step $d$ and the angular increment $\delta$. As shown in Figure 1, the tortoise shape corresponds to the following commands:

- $F(d)$: Move one step forward, step size is $d$, tortoise shape becomes $(x', y', a)$, where $x' = x + d \cos \alpha$, $y' = y + d \sin \alpha$, draw a straight line between points $(x, y)$ and $(x', y')$.
- $+(\delta)$: turn $\delta$ to the left, the next state of tortoise shape is $(x, y, a + \delta)$, and the direction of angle is anticlockwise.
- $-(\delta)$: turn $\delta$ to the right, and the next state of tortoise shape is $(x, y, a - \delta)$.

If it is used to simulate the bifurcation of Hedera nepalensis cuttages during the growth process, two new symbols need to be added, which are explained in tortoise form as follows:
The growth of Hedera nepalensis has its inherent mechanism characteristics [18]: two or more collateral branches grow from a trunk, and two or more small collateral branches grow from each collateral branch, which accords with the characteristics of fractal geometry. Therefore, the growth morphology of Hedera nepalensis can also be simulated by fractal recursive algorithm. According to the morphology of Hedera nepalensis in different reproductive stages, the generators (initial growth model) are set up, and the fractal tree is generated by recursive algorithm, which is the process of continuously redrawing the generators at a limited level. Therefore, the L-system was used to simulate the morphological description of Hedera nepalensis shoot cuttings during the growth process.

Let the initial element: $F$;
Generation rule: $FF - [-F + F - F] + [+F - F + F]$;
Compression factor: 1/3;
Angle $\delta$: 30°.

Step 1: $F$;
Step 2: $FF - [-F + F - F] + [+F - F + F]$;
Step 3: $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$ $FF - [-F + F - F] + [+F - F + F]$;
Step 4: repeat step 3 indefinitely and iterate iteratively until more realistic Hedera nepalensis graphics are generated.

In the process of recursion, the idea of string substitution of L-system can be introduced. The method is to establish a two-dimensional mathematical model of Hedera nepalensis according to the basic idea of L-system. As shown in Figure 3, starting from the main branch of Hedera nepalensis, it gradually extends to the connected branches, then proceeds the same process in a recursive way, and continues to the end. In this model, each vine branch is simplified to a straight line. Each cycle, the vine branch is scaled, rotated and moved to the position of its father vine.

L-system has many advantages, such as concise definition, high structuralization and easy implementation. However, practice has proved that the idea of string substitution is abstract, and it is not easy to control the details of Hedera nepalensis saplings cutting growth in practical programming. However, it is too rigid and cumbersome to describe the growth of Hedera nepalensis saplings cutting in programming guidance [19]. Therefore, when simulating plant morphology, it is not the best way to program only using L-system string replacement algorithm. BSP technology should be combined with L-system.

### 2.3. Combination of Fractal Theory and BSP Technology.
L-system uses the strings defined by the generating rules and replaces each character of the previous level repeatedly. In order to draw fractal graphics in computer, L-System is simple and quick solution. We have used L-system to simulate Hedera nepalensis cutting propagation and generate desired fractal image, but when it comes to more complex modeling, many manipulations are required to be done. If we have to model different plant parts, L-system does not show enough flexibility to adopt. In order to overcome this problem BSP is used on top of L-System. BSP is used in order to extend the 2-D model to 3-D space so that we can model the plant parts of Hedera nepalensis and reflect the actual spatial structure.

Hedera nepalensis image can be generated through the above process, but the generated Hedera nepalensis image is only a "pure" two-dimensional image, which cannot reflect the spatial structure of Hedera nepalensis morphology. To solve this problem, we need to introduce BSP technology [4], which is a recursive "space partition" technology [20]. In 1980, Fuchs applied it to plane-to-space partition, thus establishing a spatial binary tree structure. Because it divides the space into two parts, it can describe the objects in each part more carefully and pay more attention to the structure...
and behavior of the objects [21], so it can give full play to its advantage of "spatial division" in the simulation of Hedera nepalensis cutting propagation, and then simulate the constant in all directions. By distinguishing the left and right subtrees and drawing them randomly in succession, and describing each organ model in detail on each spatial plane with programming language, it is more realistic and natural than L-system and simple recursive backbone structure.

The fractal theory and BSP technology were used to design the simulation model of Hedera nepalensis cuttage propagation. According to the user’s needs, the interactive simulation of Hedera nepalensis cuttage propagation was carried out. By determining the necessary parameters and choosing the drawing mode, the natural and realistic Hedera nepalensis image was generated. The model includes two submodels: static simulation and dynamic simulation [22]. The dynamic submodel can simulate the dynamic growth process of Hedera nepalensis cutting propagation by determining the growth proportion of different organs [23]. In order to save different parameters of Hedera nepalensis image, a parameter database based on SQL Server 2000 was constructed, and a parameter browsing submodel was designed. At the same time, in order to make the Hedera Nepaleensis image generated can be used in most drawing tools, submodels such as comprehensive processing, image synthesis, format conversion, free drawing and picture browsing, switching demonstration, animation effect are added.

The simulation model of Hedera Nepaleensis cuttage propagation morphology is shown in Figure 4.

2.3.1. Static Simulation of Hedera Nepaleensis Morphology. Static simulation is the basis of Hedera nepalensis cutting propagation morphology simulation [24]. To simulate the propagation of Hedera nepalensis cuttings, it is necessary to investigate the mechanism and morphological differences of real Hedera nepalensis cuttings, distinguish different Hedera nepalensis organs and establish mathematical models. With the help of GDI+, integrated in NET environment, random functions are flexibly used in programming control, and a series of judgment and detail statements are added. To sum up, we should grasp the following points:

(A) Establish mathematical models for various parts of Hedera nepalensis. The main rattan can be drawn with simple straight (curved) lines, cylindrical and conical models, and can be filled with bitmap texture brushes. The fruit is filled with an elliptic model, gradient brush or path brush, as shown in Figure 5(a). Real Hedera nepalensis leaves need to be filled with closed areas and plotted with base spline curves or polygons [25], as shown in Figure 5(b). Using gradient brushes or texture brushes, fill close curve and fill polygon methods to fill colors can simulate the effect similar to that of real Hedera nepalensis leaves.

(B) Flexible use of random numbers. Random numbers should be widely used in programming process, such as whether the branches with more side rattan are on the left or right side, and the angle of each branch should have a certain random range, and the random range should be smaller than that of the bottom rattan, so that the growth of Hedera nepalensis seems more concentrated. In VB, the random number generating function Rnd () is a random number between 0 and 1, such as setting the variable RorL = Rnd (), drawing left rattan when RorL > 0.5, or drawing right rattan. By using the formula Random = Rnd () * (b - a) + a, a random number between a and b can be returned, and the deflection angle of the rattan can be expressed as
angle * Random (0.7, 1), so that it has a certain random range.

(C) Consider the apical advantage of Hedera nepalensis cutting propagation [26]. When the angle between the dividing vine and the original main vine is small, one more subvine can be drawn on the dividing vine to make the dividing vine look more stretched and denser. In the program, the judgment level statement is added to control the top advantage when the number of layers is large. At the same time, the length of each layer can be multiplied by a reduced proportion.

(D) Consider the changes of organ morphology with the number of layers. The thickness of brushes and brushes used to draw rattan branches should be related to the number of layers. The bottom rattan trunks are thicker and thinner upward. That is, with the decline of the layers, the rattan trunks become thinner gradually. At the same time, the color should also be changed. By judging the number of layers, the main rattan at the bottom is thicker. When the number of layers is less than 1, the shape and size of the leaves in different layers are also different.

(E) To differentiate different organs and use various brushes and brushes flexibly. Using the brush provided in GDI+, we can draw many kinds of vine trunks, leaves and fruits. For example, when drawing the main vine, we can use different filling methods such as Solid-Brush, Linear Gradient Brush, Texture Brush and so on to draw different effects of Hedera nepalensis cuttings reproductive morphology images.

(F) Decomposition and gradient of color. In order to make the generated image more artistic and stereoscopic, the color of each organ should be distinguished and the color depth should be flexibly configured in the control program. There are two main processing methods: one is to use Argb value with a certain random range, and the depth of each component can change to a certain extent to form a color difference; the other is to decompose the color of different organs, the method is also to use random numbers, the following procedure segment will decompose the leaf color Leavecol into yellow and green two colors.

Finally, the number of recursive layers can also be randomly reduced when drawing the upper branches and leaves, so that the generated graphics look fluctuant and consistent, closer to the true form of Hedera nepalensis.

2.3.2. Dynamic Simulation of Hedera Nepalensis Morphology.
Dynamic simulation corresponds to static simulation, and this submodel can be used to demonstrate the dynamic growth of Hedera Nepalensis cuttings. In the process of dynamic simulation, the control parameters are first determined by tabs to generate the initial shape of the simulated Hedera Nepalensis. Then, the growth proportions of each component organ (such as the ratio of leaf length, leaf width, rattan length, rattan diameter and amplitude angle) and the growth coefficients of the control parameters (such as recursive depth, initial sitting position) are determined. The standard and step size can be used to generate the image of Hedera nepalensis cuttings propagation continuously from the dynamic control parameters, and simulate the dynamic growth process of Hedera nepalensis cuttings propagation, such as Hedera nepalensis from thin to thick, from low to high, and from small to large. In the process of Hedera nepalensis cuttings propagation, the proportion coefficients of growth of each organ can be determined quantitatively according to the actual growth conditions of Hedera nepalensis, such as photosynthesis, watering, fertilization, temperature, humidity, and other external factors [27].

2.3.3. Design of Parameter Database.
In order to realize the functions of storing and browsing control parameters and generating images, a parameter database tree data is established by using SQL Server 2000, which includes six data tables, corresponding to each parameter browsing interface [28]. In the static generation submodel, Hedera nepalensis images and all parameters can be generated by setting the number stored in the database, and stored in the corresponding data table. In the parameter browsing interface, browsing, modification, output and other operations can be carried out. The design of TabLB is shown in Table 1. The field designs of other tables are roughly the same.
3. Results

3.1. Graphics Generation Experiments. The experiment used the fractal theory-based Hedera nepalensis cutting propagation simulation method to generate Hedera nepalensis graphics, the process is shown in Figure 6 below. From Figure 6, it can be seen that Hedera nepalensis can be effectively generated by using this method.
Table 2: Comparison of simulation results by different simulation methods.

| Simulation phase | Simulation method | Actual growth length/cm | Actual growth height/cm | Simulated growth length/cm | Simulated growth height/cm | Length fitting error/% | Height fitting error/% |
|------------------|-------------------|--------------------------|-------------------------|---------------------------|---------------------------|------------------------|------------------------|
| The first week   | BSP simulation method | 6.22                     | 8.31                    | 6.39                      | 8.10                      | 2.73                   | 2.53                   |
|                  | L-system simulation method | 6.22                     | 8.31                    | 6.04                      | 8.08                      | 2.89                   | 2.77                   |
|                  | The method in this paper | 6.22                     | 8.31                    | 6.18                      | 8.27                      | 0.64                   | 0.48                   |
| The second week  | BSP simulation method | 10.37                    | 10.68                   | 10.81                     | 10.42                     | 4.24                   | 2.43                   |
|                  | L-system simulation method | 10.37                    | 10.68                   | 9.86                      | 10.98                     | 4.92                   | 2.81                   |
|                  | The method in this paper | 10.37                    | 10.68                   | 10.32                     | 10.63                     | 0.48                   | 0.47                   |
| The third week   | BSP simulation method | 16.25                    | 13.74                   | 16.02                     | 14.17                     | 1.42                   | 3.13                   |
|                  | L-system simulation method | 16.25                    | 13.74                   | 16.73                     | 13.22                     | 2.95                   | 3.78                   |
|                  | The method in this paper | 16.25                    | 13.74                   | 16.18                     | 13.66                     | 0.43                   | 0.58                   |
| The fourth week  | BSP simulation method | 25.14                    | 15.23                   | 25.69                     | 15.00                     | 2.19                   | 1.51                   |
|                  | L-system simulation method | 25.14                    | 15.23                   | 24.80                     | 14.87                     | 1.35                   | 2.36                   |
|                  | The method in this paper | 25.14                    | 15.23                   | 25.08                     | 15.31                     | 0.24                   | 0.53                   |
| The fifth week   | BSP simulation method | 43.14                    | 16.75                   | 44.79                     | 17.12                     | 3.82                   | 2.21                   |
|                  | L-system simulation method | 43.14                    | 16.75                   | 42.21                     | 17.24                     | 2.16                   | 2.93                   |
|                  | The method in this paper | 43.14                    | 16.75                   | 43.46                     | 16.63                     | 0.74                   | 0.71                   |

Figure 7: Graph showing actual and simulated growth of hedera nepalensis in five weeks.
and the shape of Hedera nepalensis is vivid and realistic, which conforms to the growth law of Hedera nepalensis.

3.2. Comparison of Simulation Results. Five successful Hedera nepalensis plants were selected to compare the length and height of Hedera nepalensis obtained by different simulation methods on the basis of the same actual growth conditions of Hedera nepalensis. The comparison results are shown in Table 2.

The Figure 7 shows the graph of actual growth and simulated growth Hedera nepalensis in five weeks. Analysis Table 2 shows that three different methods are used to simulate the propagation stage of Hedera nepalensis cuttings. The simulation accuracy of this method is the highest. The simulation error of the fifth week is the highest in the simulation stage of Hedera nepalensis cuttings, and the length error and height error are 0.74% and 0.71%, respectively. The error of the other two methods in simulating different stages of Hedera nepalensis cuttings is between 1.35% and 4.92% respectively. The comparison results show that the accuracy of this method in simulating the propagation process of Hedera nepalensis cuttings is higher.

3.3. Performance Comparison of Different Methods. In order to compare the simulation methods applied to Hedera nepalensis cuttage propagation and verify the performance advantages of this method, the recursive depth was set to 4, 5, 6 and 7 respectively under the condition of the same step size. The effect of different simulation methods to generate graphics and related indicators were compared. The results are shown in Table 3.

Analysis Table 3 shows that there are two indicators for comparison of different simulation methods, one is the generation time of graphics and the number of generated nodes. The generation time of images objectively represents the time complexity of simulation methods. In programming, Tick attributes are acquired by setting the difference of Tick attributes at the beginning of drawing and at the end of drawing, in milliseconds; the other is generated by setting the difference of Tick attributes at the end of drawing. The number of nodes can represent the structural complexity of generating Hedera nepalensis. The more nodes, the more complex the Hedera nepalensis structure is. In programming, a recursive accumulator can be set up in the drawing submodel, in units. By comparing the three different simulation methods, the following conclusions can be drawn: the number of nodes of the three simulation methods increases with the increase of recursive depth, and the generation time fluctuates; the generation time of BSP simulation method increases the most, while the generation time and the number of nodes of L-system simulation method increase by numbers. The performance of this method is superior to that of the other two methods. Taking recursive depth 7 as an example, the time of generating graphics in this method is similar to that of L-system simulation method, which saves about 1/3 compared with BSP simulation method, while the number of generated nodes is about 8.5 times that of BSP simulation method. It shows that this method not only has the characteristics of BSP simulation method, which is easy to describe details and control, but also has the advantages of L-system simplicity and high efficiency.

The following Table 4 shows the accuracy of our simulated results.

4. Discussions

This paper studies the simulation method of Hedera nepalensis cuttage propagation based on fractal theory and simulates the process of Hedera nepalensis cuttage propagation with L-system and BSP algorithm. The simulation results show that on the basis of ensuring the effective generation of Hedera nepalensis graphics, this method has the characteristics of high simulation accuracy and easy to describe details, is easy to control, and has the advantages of simplicity and efficiency.

Fractal is the best language to describe the morphology of natural plants. Fractal recursive algorithm is the closest algorithm to describe the basic fractal features. The self-similarity, self-replication, and self-nesting fractal features of natural plants also determine that recursive algorithm is the most basic choice to simulate plant morphology. Fractal L-system is simple, efficient, and highly structured, while BSP algorithm has the function of partitioning space.
Therefore, by combining fractal algorithm with BSP method and using it as a programming idea, we can control and depict the details of each organ of Hedera nepalensis in each spatial plane by dividing the spatial plane recursively in the program, so that the generated graphics can better reflect the spatial structure characteristics of Hedera nepalensis.

Establishing reasonable models for Hedera nepalensis organs is the basis of describing its details. Hedera nepalensis is composed of main rattan, branches, leaves, fruits and other organs. Establishing a reasonable mathematical model for each organ of Hedera nepalensis is the basis of programming. Only by programming the different models of each organ can the details of each part of Hedera nepalensis be controlled, and by extracting parameters separately, the simulation and interactive control of Hedera nepalensis morphology can be realized.

Faithful to the actual growth mechanism of Hedera nepalensis cuttings, programming is the basis to ensure the simulation effect. In order to make the generated Hedera nepalensis image closer to the real Hedera nepalensis, it is necessary to process such as top edge, color difference and hierarchy in programming. The growth mechanism of Hedera nepalensis under different environmental conditions was studied quantitatively, and its growth proportion coefficient was determined to realize the dynamic simulation control of cutting propagation close to the real Hedera nepalensis.

5. Conclusions

The establishment of fractal theory provides a powerful means for the simulation of plant morphology. This paper studies the simulation method of Hedera nepalensis cutting propagation based on fractal theory. Combining L-system string substitution idea with original fractal recursive algorithm, BSP method is used to divide the spatial plane, which can describe and control the details of Hedera nepalensis organs on the basis of establishing geometric models. With the help of the brush and brush in GDI+ and the flexible use of random functions, the Hedera nepalensis graphics of different stages in the process of Hedera nepalensis cutting propagation can be simulated vividly. The composition of generators is represented by strings, and Hedera nepalensis fractal images are generated repeatedly by recursive algorithm. The different Hedera nepalensis organs are distinguished by static simulation and the mathematical model is established. With the help of GDI+, random functions are flexibly used in programming control to simulate the process of Hedera nepalensis cutting propagation. By determining the growth proportion coefficient of each organ and the growth coefficient of control parameters, the image of Hedera nepalensis cutting reproduction is generated continuously from the dynamic control parameters and the dynamic process of Hedera nepalensis cutting reproduction is simulated. The simulation results show that the simulation error of this method is less than 0.8%. The simulation process is simple and efficient, and the simulation results are vivid and viable to suggest newer solution for Hedera nepalensis cutting propagation to protect the environment.

Data Availability

The data can be made available on valid request.

Conflicts of Interest

The authors have nothing to declare as conflicts of interest.

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