Construction and Visualization of Wheat Roots Model Based on Artificial Life

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***Abstract*—In the paper, two important virtual plant modeling methods, dual-scale automata and L-system, are introduced firstly. According to structure characteristics of wheat root, the morphological structure model of wheat root is then constructed using combination of dual-scale automaton and L system. In view of the environment factors that affect growth of wheat roots, we construct the growth restricted model of wheat roots, and combine it with morphological structure model. The dynamic growth simulation of wheat root is obtained.**

***Index Terms*—artificial life, wheat roots, dual-scale automaton, L system, growth restricted model**

I. INTRODUCTION

With the development of computer graphics, people have been exploring the computer simulation of natural scenery. Especially in recent years, the computer simulation of nature scenery has been one of challenging issues in computer graphics [1]. Plant growth is divided into ground parts of growth and underground parts of roots growth. Due to the roots system hides under the ground, it has limitation to measure techniques and theoretical approaches. Also, due to roots system does not have obvious signs of growth as plant above ground, and is not easy to divide roots growth into basic unit. Therefore, it is difficult to model for the growth of roots structure [2]. Although researchers have developed a lot of models about roots structure [3] [4], the research on roots is still far lags behind the research on ground parts of plants.

II. DUAL-SCALE AUTOMATON AND L SYSTEM

Both domestic and abroad research on virtual plant has made some achievements. They set up a number of modeling methods, such as iterated function, particle system, dual-scale automaton and L system, etc. Among them, the two important methods are dual-scale automaton and L system.

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A. Dual-scale Automaton

Dual-scale automaton is an automaton model which has two scales of "micro-state" and "macro-state". In the simulation process of plant growth, it is generally simulated according to a certain time interval and a certain scale unit [5]. Due to leaf element is a plant meristem unit, we use "micro-state" to represent leaf element as the minimum unit in the model of dual-scale automaton, as shown in figure 1.

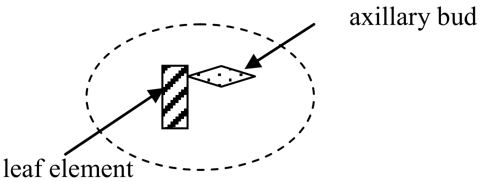

Figure 1 Micro-state

In the figure of micro-state,  denotes leaf element,  denotes axillary bud that is likely to generate on the leaf element. It uses different color or filled pattern to denote different physiological age. Plant growth is a cyclical process, each cycle is called a growth cycle. In a growth cycle, the sum of new leaf element that plant outgrow in the axis is called grow unit. In the model of Dual-scale automaton, we use "macro-state" to represent growth unit. Due to growth unit is made up of leaf elements, macro-state is made up of many micro-states, also the leaf elements in the same one growth unit are in the same physiological stage, therefore the micro-states in the same one macro-state will have the same physiological age, as shown in figure 2.

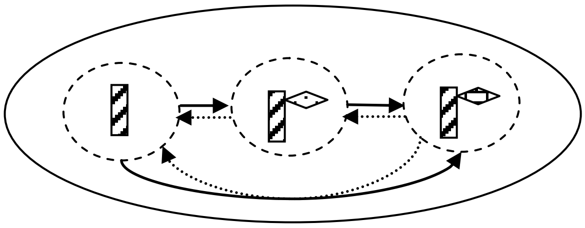

Figure 2 Macro-state including three micro-states

Dual-scale automaton simulates the process of plant growth and builds the plant's topology through the combination and circulation of the two states.

B. L System

The theory of L system was proposed in 1968 by Lindenmayer [6], an American biologist. It uses formalized language to describe structure and growth of plant, uses end symbol of the language comparative to the structure of plant. The sentence created by grammar denotes plant, and the middle process of sentence creating is the process of plant growth. It uses process other than function equation to construct model of plant. In the application of build plant graph, it emphasizes particularly on express of topology structure.

The essence of L system is a parallel rewriting system. It can generate complex graphics through experiential generalization and abstract for growth process of plant, construction of axiom (initial state) and production set (describe rules), and a limited iteration for character string.

For establishment of integrate and available plant model, L system continually expands its functionality. The early L system is briefly named as determined L system. It is a ordered triples $L=<V,\omega,P>$, V denotes alphabet, V* denotes all the words based on V (character string making up of symbol or character), ω is a non-empty word called axiom (or original element), P is finite collection of generation rules, generation rule writes $c \rightarrow s$, letter c and word s are separately called precursor and subsequence of generation formula. It prescribes that any letter $c \in V$, it at least exists one non-empty s, so as to make $c \rightarrow s$. if the given precursor $c \in V$ dose not have specific generation formula, it prescribes $c \rightarrow c$ that belongs to P.

L system must get hold of a string composed of specific letters in the end. In order to indicate that the string has a certain meaning, when describing some graphs, it needs to give every character a specific graphic meaning in the L system. Generally, we use "algorithm of turtle running", a mathematics model of L system, to interpret it. Its basic idea is that supposing that one turtle crawls on the plane, its state uses three value to denote, written as (x, y, θ). Descartes coordinate (x, y) denotes a right angle coordinate of turtle's position, direction angle θ denotes direction of turtle's head. Then we give the turtle crawling step d and torsion direction's angle increase δ. The graphic interpretation of several kinds of symbol is as follows in figure3.

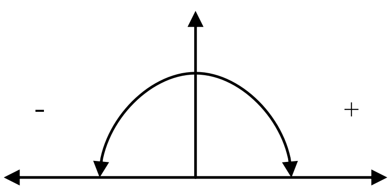

Figure 3 Interpretation of character F, +, -

F(d): move forward one-step, the length of step is d. The state of turtle change to (x', y', θ), $x'=x+d\cos\theta$, $y'=y+d\sin\theta$; The graphic interpretation is to draw a straight line from point (x, y) to point (x', y');

+ (δ): turn left δ , the next state of the turtle's shape is $(x, y, \theta+\delta)$, the angle positive direction is anti-clockwise direction.

-(δ): turn right δ , the next state of the turtle's shape is $(x, y, \theta-\delta)$, the angle negative direction is clockwise direction.

Where d, θ,δare parameters that can be changed.

The above turtle interpretation of string is two-dimensional. Due to plant growth is three-dimensional, it needs to be extended to three-dimensional turtle interpretation. In order to make string to be three-dimensional turtle interpretation [8], the key is to redirect three-dimensional space. It uses three vectors H, L and U to denote the current orientation of space turtle. H denotes direction of turtle's head, L denotes left, U denotes up. These vectors have unit length and the direction orthogonal, namely meeting equation $H \times L = U$. The rotation of turtle can be expressed by equation (H, L,U)=(H,L,U) R, R is a 3×3 rotation matrix. Specially, the rotation matrix that vectors H, L and U rotate α can be expressed as follows:

$$R_H(a) = \begin{bmatrix} \cos a & \sin a & 0 \\ -\sin a & \cos a & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_L(a) = \begin{bmatrix} \cos a & 0 & -\sin a \\ 0 & 1 & 0 \\ \sin a & 0 & \cos a \end{bmatrix}$$

$$R_U(a) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos a & -\sin a \\ 0 & \sin a & \cos a \end{bmatrix}$$

The following symbols control the direction of space turtle:

$+(\theta)$: turn left θ ,rotation matrix is $R_U(\theta)$.

$-(\theta)$: turn right θ ,rotation matrix is $R_U(-\theta)$.

$\&(\theta)$: go around L, turn down θ ,rotation matrix is $R_L(\theta)$.

$\Lambda(\theta)$: go around L, turn up θ ,rotation matrix is $R_L(-\theta)$.

$\backslash(\theta)$:go around H, scroll to left θ ,rotation matrix is $R_H(\theta)$.

$/(\theta)$:go around H, scroll to right θ , rotation matrix is $R_H(-\theta)$.

$|(\theta)$:go around U, turn back 180°,rotation matrix is $R_U(180^\circ)$.

Space direction and rotation diagram are shown in figure4.

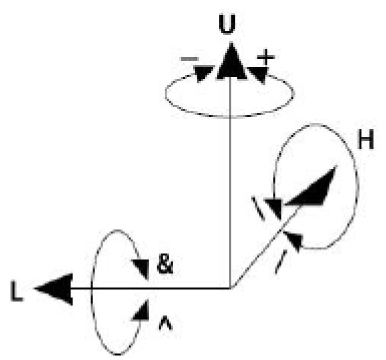

Figure 4 Space direction and rotation diagram

In order to formally describe branch structure of many plants, Lindenmayer introduces bracket string structure, namely:

[: put the current states of turtle in stack, the information in the stack includes the position and direction of turtle, and the color, width and so on of line that is about to draw.

]: get a state from stack, as the current state of turtle. Though the position of turtle changed, it does not draw any line.

The characteristics of modeling by dual-scale automaton are intuitive at a glance. The benefits of modeling by L system is that the description of plant's topology can be easily converted into a language that computer can identify. Therefore, adopting both methods at the same time can greatly improve efficiency.

III. Construction of Wheat Roots Morphology Model

A. Division of Structure Unit of Wheat Roots

Similar to the concept of basic growth unit division of plant [5] [9], root element is regarded as the smallest structure growth unit of roots system. There are apical meristem and lateral primordium in the root element. They will possibly form a new root element in the future. A unit effective temperature T0 is used to characterize the required time of root element growth, known as growth cycle of root element, and the physiological age of root element is used to characterize types of various root individuals.

B. Micro-state of Wheat Roots

We use the micro-state of dual-scale automaton to describe root element. The description of micro-state of root element is corresponding to that on micro-state of leaf element on the ground part of plant. In the micro-state of root element, rectangle with pattern is used to denote root element, round with pattern is used to denote lateral primordium, as shown in figure 5.

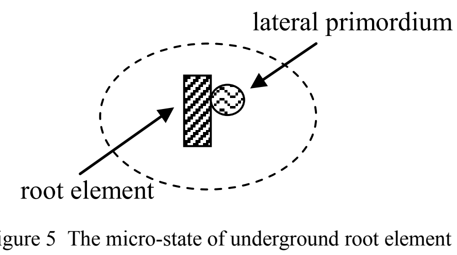

Figure 5 The micro-state of underground root element

In the description of automaton model underground part of plant, it assumes that the physiological age of micro-state is equivalent to the root element's own physiological age.

C. Macro-state of Wheat Roots

We use the macro-state of dual-scale automaton to describe root individual or root axis. Due to root individual or root axis consists of root elements, the macro-state is made up of many micro-states. The same root individual or root axis consists of the same types of root elements, therefore, each micro-states that compose the same macro-state have the same physiological state. The physiological age of macro-state is equivalent to that of its micro-states.

For the difference with the micro-state, the macro-state is surrounded using real line, as shown in figure 6.

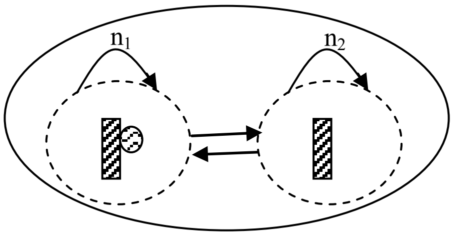

Figure 6 The macro-state containing two micro-states

In order to easily translate the dual-scale automaton model of wheat into L system grammar later, the color (filling pattern) in the dual-scale automaton is changed into physiological age denoted by digital ID or organs denoted by characters etc, which are pre-defined special parts, as shown in figure 7.

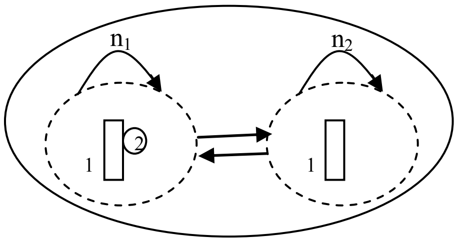

Figure 7 Improved dual-scale automaton model

The micro-states in the macro-state denote with 1, indicating that its physiological age is 1 or the root type is 1. Rectangle denotes root segment. The number 2 in the circle denotes the physiological age of root that will outgrow from lateral primordium in the next growth cycle.

D. Morphology Model of Wheat Roots

1) Growth characters of wheat roots.

Wheat roots are made up of primary roots, secondary roots and lateral roots[10]. The root developed from embryo of seed is called primary root. There are general 3 to 5 primary roots, and no more than 7. The root developed from tillering node and the section is called secondary root. The more the wheat tillering nodes have, the more the secondary roots have. When the primary roots and secondary roots grow for a certain time, new root will grow on them, it is called first level lateral root. First level lateral root can generate hypo-level branch, that is, second level lateral root, and so on.

2) Dual-scale automaton model of wheat roots.

From the above analysis, the root types in wheat roots are as follows: primary roots, secondary roots, first level lateral roots and second level lateral roots, etc. The micro-states and macro-states in the automaton should include the relationship between all kinds of root elements of wheat roots, as well as process of overall structure change of roots. In order to simulate the continuous changes in the process of roots structure, two-assisted virtual type of root elements are added to describe the succession of primary root and secondary root in the roots, respectively.

In the wheat roots automaton model, the physiological age of the virtual root element that generates primary roots is set to A1, the physiological age of the virtual root element that generates secondary roots is set to A2, the physiological age of primary roots is 1, the physiological age of secondary roots is 2, the physiological age of their two kinds first level lateral roots are 3 and 4, respectively, and the physiological age of their two kinds second level lateral roots are 5 and 6, respectively, as shown in figure 8.

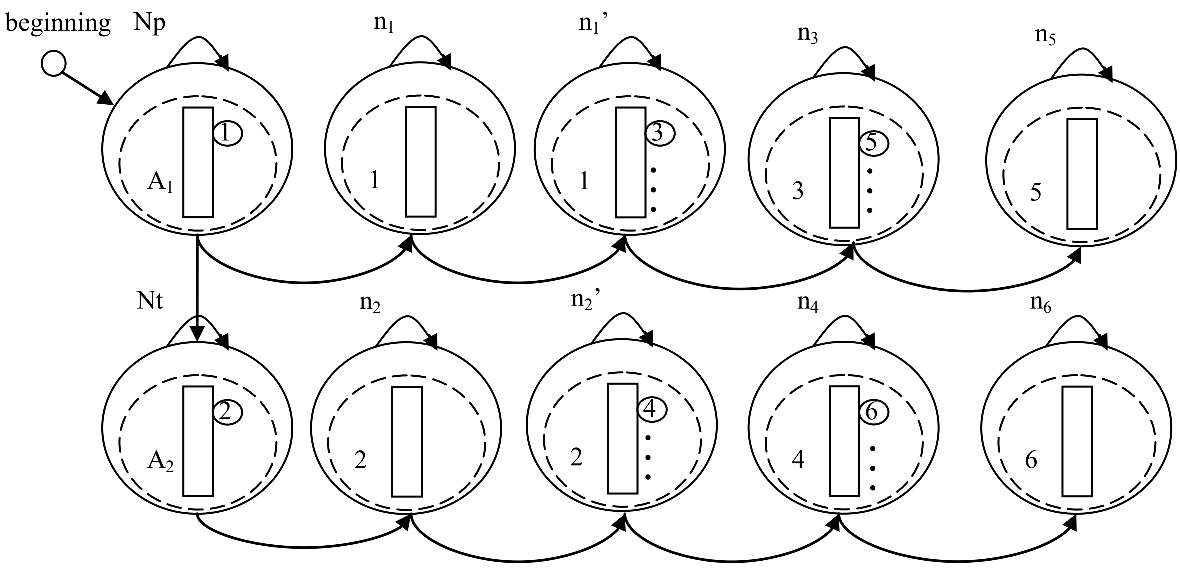

Figure 8 The dual-scale automaton model of wheat roots

3) The translation of dual-scale automaton model of wheat roots into L grammar.

The symbols used in L system are made agreement as follows: V1 denotes virtual root element that gives birth to primary roots; V2 denotes virtual root element that gives birth to secondary roots; A1 denotes primary roots that their physiological age is 1; A2 denotes secondary roots that their physiological age is 2; A3, A4, A5 and A6 denote lateral roots that their separately physiological age are 3, 4, 5 and 6; I denotes root segment.

The dual-scale automaton model of wheat roots is translated into L grammar, shown as follows:

Axiom: V1 (Np, 0)

Production:

P1: V1 (n, t) →V1 (n, t+dt) //Survival time of virtual root element that generates primary roots extends dt at each iterative process

P2: V2 (n, t) →V2 (n, t+dt) // Survival time of virtual root element that generates secondary roots extends dt at each iterative process

P3: A1 (n, t) →A1 (n, t+dt) // Survival time of primary roots extends dt at each iterative process

P4: A2 (n, t) →A2 (n, t+dt) // Survival time of secondary roots extends dt at each iterative process

P5: A3 (n, t) →A3 (n, t+dt) //Survival time of first lateral roots of primary roots extends dt at each iterative process

P6: A4 (n, t) →A4 (n, t+dt) //Survival time of first lateral roots of secondary roots extends dt at each iterative process

P7: A5 (n, t) →A5 (n, t+dt) //Survival time of second lateral roots of primary roots extends dt at each iterative process

P8: A6 (n, t) →A6 (n, t+dt) //Survival time of second lateral roots of secondary roots extends dt at each iterative process

P9: I (t) →I (t+dt)

P10: V1 (n, t): n>0 → [A1 (n_1, 0)] V1 (n-1, 0)//It doesn't generate root segment, just primary root

P11: V1 (n, t): n=0 → [V2 (Nt, 0)] V1 (n-1, 0) //When primary roots grow for a certain time, it begins to generate secondary roots

P12: V1 (n, t): n<0→φ //It doesn't generate primary roots

P13: V2 (n, t): n>0 →[A2 (n_2, 0)] V2 (n-1, 0) //It generates secondary roots

P14: V2 (n, t): n<=0→φ

P15: A1 (n, t): n>0→I(t) A1 (n-1, 0) //Primary roots are growing, but don't generate their lateral roots

P16: A1 (n, t): n=0→A1'(n_1', 0) A1 (n-1, 0)

P17: A1 (n, t): n<0→φ

P18: A1'(n, t):n>0→I(t)/(θ)[A3 (n_3, 0)]… [A3 (n_3, 0)] A1'(n-1, 0) //Primary roots are growing and generate their first level lateral roots

P19: A1'(n, t):n<=0→φ

P20: A2 (n, t): n>0→I(t) A2 (n-1, 0) //Secondary roots are growing, but don't generate their lateral roots

P21: A2 (n, t): n=0→A2' (n_2', 0) A2 (n-1, 0)

P22: A2 (n, t): n<0→φ

P23: A2'(n, t): n>0→I(t)/(θ)[A4 (n_4, 0)]… [A4 (n_4, 0)] A2' (n-1, 0) //Secondary roots are growing and generate their first level lateral roots

P24: A2'(n, t): n<=0→φ

P25: A3 (n, t): n>0→I (t)/(θ)[A5 (n_5, 0)]… [A5 (n_5, 0)] A3 (n-1, 0)

P26: A3 (n, t): n<=0→φ//First level lateral roots of primary roots are growing and generate their second level lateral roots

P27: A4 (n, t): n>0→I (t)/(θ)[A6 (n_6, 0)]… [A6 (n_6, 0)] A4 (n-1, 0)

P28: A4 (n, t): n<=0→φ//First level lateral roots of secondary roots are growing and generate their second level lateral roots

P29: A5 (n, t): n>0→I(t) A5 (n-1, 0) //Second level lateral roots of primary roots are growing

P30: A5 (n, t): n<=0→φ

P31: A6 (n, t): n>0→I(t) A6 (n-1, 0) //Second level lateral roots of secondary roots are growing

P32: A6 (n, t): n<=0→φ

In this L system, P1 to P8 denote that the survival time of primary roots, secondary roots and their first level lateral roots and second level lateral roots extend dt at each iterative process; P10 and P12 denote that primary roots are generated; P11 denotes that secondary roots are generated when primary roots are growing for a certain time; P13 and P14 denote that secondary roots are generated; P15, P16 and P17 denote that primary roots are growing but don't generate branch; P18 and P19 denote that primary roots continue to grow and generate their first level lateral roots; P20, P21 and P22 denote that secondary roots are growing but don't generate branch; P23 and P24 denote that secondary roots continue to grow and generate their first level lateral roots; P25 and P26, P27 and P28 denote that their two kinds first level lateral roots are growing and generate their second level lateral roots, respectively; P29 and P30, P31 and P32 denote that their two kinds second level lateral roots are growing, respectively.

IV. Construction of Growth Restricted Model of Wheat Roots and Its Combination with Morphological Structure Model of Wheat Roots.

Besides their own growth factors, the environmental factors have significant impact on the growth of plant wheat roots. In the paper, we study the effects on growth of wheat roots from the environment, constructing growth restricted model of wheat roots and combining morphological structure model of wheat roots with growth restricted model.

A. The Growth Restricted Model of Wheat Roots

In this paper, different soil moisture content is selected as the restricted condition on the study of wheat roots growth. In addition, taking the factors that impact on the growth direction of wheat roots into consideration, we construct the growth restricted model of wheat roots [11].

(1) The number of main root

Main root is made up of primary root and secondary root. Once primary root generates, their number is relatively stable, subjection to environmental impact is little. Model of the number of primary root is set up as follows:

$$Np = 5 \quad (t > 0 \quad \omega \geq 0.6) \qquad (4.1)$$
$$Np = 4 \quad (t > 0 \quad \omega < 0.6)$$

In the formula: *Np* is the number of primary root.

The growth and development of secondary root is shown as an obvious "s"-type process throughout the growth period. The growth model of the number of secondary root is set up as follows:

$$Nt = (61.538t - 6.1538)\omega \quad (t \leq 0.75) \qquad (4.2)$$
$$Nt = (-800t^2 + 1360t - 530)\omega \quad (t > 0.75)$$

In the formula, *N*t is the number of secondary root at the time of *t*, *t* is comparatively growth time, ω is soil moisture content.

(2) The growth of main root in root system

The main root is the foundation and framework in root system. The maximum depth that primary root and secondary root of wheat take root is

$$L\max = k/ae^{-bt} \qquad (4.3)$$

In the formula, $L\max$ is the maximum depth that main root takes root, *t* is comparatively growth time (0-1), a, b, k are constant coefficients.

(3) Branching coefficients of main root

Branching coefficient of the first lateral root shows obviously a "cycle" equation distribution:

$$\begin{cases} I_{pb} = A_P t^{B_P} e^{C_P t} & (t > 0.1); \\ I_{ab} = A_a t^{B_a} e^{C_a t} & (t \geq 0.2); \\ I_{ab} = 0 & (t < 0.2), \end{cases} \qquad (4.4)$$

In the formula, I_{Pb} is branching coefficient of the first lateral root of primary root; I_{ab} is branching coefficient of the first lateral root of secondary root; $A_P, B_P, C_P, A_a, B_a, C_a$ is constant coefficient; The comparatively time that secondary root starts to branch is 0.2.

(4) The largest elongation of lateral root

Elongation of lateral root changes as depth of taking root. At random relative depth, the length of first lateral root of primary root:

$$L_{Pl}(D,t) = L_{p\max}(t) / \left(A_P + B_p D + C_P D^2\right) \quad (t > 0) \qquad (4.5)$$

The length of first lateral root of secondary root:

$$L_{al}(D,t) = L_{a\max}(t) / \left(A_a + B_a D + C_a D^2\right) \quad (t \geq 0.2)$$
$$L_{al}(D,t) = 0 \quad (t < 0.2) \qquad (4.6)$$

In the formula, $L_{p\max}(t)$ and $L_{pl}(D,t)$ is the depth that the main root of primary root takes root at the time of t and the length of its first lateral root in the relative depth D, respectively. A_p, B_p, C_P is constant coefficient; $L_{a\max}(t)$ and $L_{al}(D,t)$ is the depth that the main root of secondary root takes root at the time of t and the length of its first lateral root in the relative depth D, respectively . A_a, B_a, C_a are constant coefficient.

(5) The maximal branch-free length coefficient

The maximal branch-free length coefficient for primary root is

$$L_{pn} = 0.3488612 + 0.2349307\,t - 0.6437824\,t^2 \qquad (4.7)$$

The maximal branch-free length coefficient for secondary root is

$$L_{an} = 0.169t^{2.305} \qquad (4.8)$$

In the formula, $L_{pn} = L_{pm}(t)/L_{p\max}(t)$, $L_{pm}(t)$ is the largest length that primary root don't branch at the time t, $L_{p\max}(t)$ is the length that primary root takes root at the time of *t*; $L_{an} = L_{am}(t)/L_{a\max}(t)$, $L_{am}(t)$ is the maximal length that secondary root doesn't branch at the time *t*, $L_{a\max}(t)$ is the length that secondary root takes root at the time of t.

(6) Growth direction

The growth trajectory of wheat roots is not straight, which is influenced by many factors. Its growth direction model, as shown in figure 9, includes random deviation of previous root growth direction, geotropism and soil resistance gradient [12].

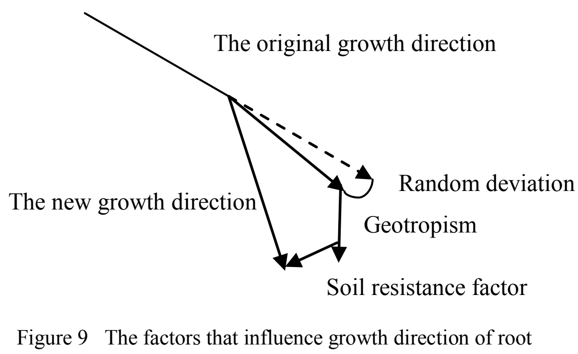

Figure 9 The factors that influence growth direction of root

It supposes that the growth direction of root in its previous cycle is known, which is expressed by vector in the three-dimensional space, it is expressed by cosine function of a straight line in which the root direction lies, i.e.,

$$D_{N-1} = \left(\cos(\alpha_{N-1}), \cos(\beta_{N-1}), \cos(\gamma_{N-1})\right)$$

Based on previous growth direction, the root also has an effect of vector that points to the earth's core, the vector is

$$D_G = (0,0,\tau_N)$$

In the formula, τ_N is the adjustment coefficient of root geotropism.

Random deviation is a small angle of the axial and radial on the basis of previous direction. A vector of amendment that has little impact on growth direction is derived as

$$D_N^{'} = \left(\cos\left(\alpha_N^{'}\right), \cos\left(\beta_N^{'}\right), \cos\left(\gamma_N^{'}\right)\right)$$

According to the computing rules of space vector, summing all vectors, the new extension direction of root is gained as

$$D_N = D_{N-1} + D_G + D_N^{'}$$

B. The Combination of Morphology Structure Model and Growth Restricted Model of Wheat Roots

In the morphology structure model of wheat root, it's necessary to determine the parameters as follows. Np: the number of primary root, Nt: the number of secondary root, n_1 and n_2: the periodicity that the not branching parts of primary root and secondary root grow to need, n_1' and n_2': the periodicity that the branching parts of primary root and secondary root grow to need, n_3 and n_4: the periodicity that the first lateral roots of primary root and secondary root grow to need, n_5 and n_6: the periodicity that the second lateral roots of primary root and secondary root grow to need.

Through the analysis of factors that have impacts on growth of wheat roots, the growth restricted model has been constructed. Now the combination of morphology structure model and growth restricted model of wheat roots is as follows: given the values of soil moisture content ω and comparatively time t, from (4.1), we gain the number of primary root N_P, from (4.2), we gains the number of secondary root N_t. According to (4.7) and (4.8), we compute the branch-free length of primary root and secondary root, then from the formula $n_1 = L_{pm}(t)/d$ and $n_2 = L_{am}(t)/d$, we determine the periodicity that the branch-free parts of primary root and secondary root grow to need at the time of t, d is the simulation step. According to (4.3), we compute the rooting depth for primary root and secondary root at the time of t, then from the formula $n_1^{'} = L_{p\max}(t)/d - n_1$ and $n_2^{'} = L_{a\max}(t)/d - n_2$, we determine the periodicity that the branching parts of primary root and secondary root grow to need at the time of t. From (4.4), we compute the branching number of primary root and secondary root. According to (4.5) and (4.6), we compute the length of the first lateral of primary root and secondary root, the from $n_3 = L_{pl}(D,t)/d$ and $n_4 = L_{al}(D,t)/d$, we determine the needed growth periodicity for the two kinds of first lateral root at the time of t. The computation of n_5 and n_6 is the same as above. The angle of root growth can be computed by the formula $D_N = D_{N-1} + D_G + D_N^{'}$.

V. THE REALIZATION OF WHEAT ROOTS VISUALIZATION

Based on the above model of wheat root growth, VC++ as the development platform, combined with technology of OpenGL three-dimensional graphics library, the wheat roots are simulated, the growth of wheat roots are three-dimensional dynamically simulated on the computer.

The algorithm of simulating wheat roots morphology is simply described as follows:

```
Sub Recursion (n)
    If recursive depth equal to 0
        Then exits this subprogram;
    Else
        It draws a root segment;
        It turns a certain angle;
        Recursion (n-1);
        It draws branch root;
    End if
End Sub
```

The running interface of simulation program for wheat roots growth is shown in figure 10.

Figure 10 The running interface of simulation program for wheat roots growth

In the different soil moisture content conditions and when the comparatively growth time is 0.7, the growth and development status of wheat roots are shown in figure11.

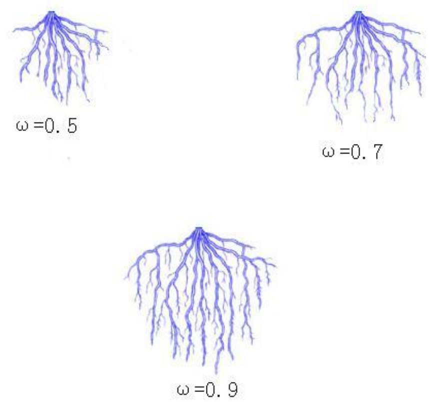

Figure 11 The growth simulation of wheat roots on different soil moisture content conditions

VI. Conclusion

In this paper, morphology model of wheat roots is constructed using the method of combining dual-scale automaton with L system. Then taking into account factors that have impact on growth of wheat root, such as soil moisture content and comparative growth time, and so on, we construct the growth restricted model of wheat roots, and combine it with morphology structure model, then realize growth simulation of wheat roots. The results accord with the actual growth law of wheat roots. The method owns the characteristics of both dual-scale automaton and L system. Its model is intuitive, easy to be identified by computer. Therefore, adopting the proposed method can greatly improve simulation efficiency.

In the following research work, we will take other factors that have impact on wheat roots growth into account, further studying the growth law of wheat roots. The research will play a great role in promoting on wheat yield and agriculture development.

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