Wheat Three-Dimensional Reconstruction and Visualization System

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Abstract. The study object is wheat. Through the observation and analysis on the morphological structure of wheat plant, the concepts of macrostate, substate and microstate are put forward, the wheat growth mechanism model is established, and thus the description and control of wheat morphogenesis process could be realized. Based on the branch structure characteristics of plant, the wheat morphological data model based on axis structure is proposed to realize the structural storage of plant topological structure and organ morphological feature data. On this basis, based on the thought of "growth model - morphological feature model - geometric modeling - display model", the technical framework of wheat form visualization is established and on the VC++ platform, the virtual wheat growth system is built with OpenGL. The running result of the system shows that wheat morphological feature can be well simulated with the system to realize the virtual display of the growth process in the individual growth period of wheat.

Keywords. Wheat; Plant morphological; Virtual; Visualization

1 Introduction

Virtual plant has been the research hotspot in digital agriculture, virtual reality and other interdisciplinary fields. It is aimed at revealing the complex relationship among plant growth, physiological process and environmental factors with a dynamic and visualized virtual scene,

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therefore, it has bright prospect in agriculture, forestry, ecology and remote sensing. A lot of researches have been carried out on virtual plants at home and abroad. Among them, in terms of the reconstruction of plant morphological structure, L system established by the University of Calgary, Canada[1], the AMAP system by CIRAD in France[2] and the dual-scale automata proposed by Sino-French Laboratory of Institute of Automation, Chinese Academy of Sciences[3] and so on are included. L system focuses on the expression of plant topological structure, and describes plant morphology and growth pattern with abstract rules, but its defect lies in that it is too complex, and it is very difficult to extract and define the growing rule of a specific type of plant. AMAP and dual-scale automata can well describe the plant physiological feature and growth process, however, AMAP is suitable for modeling tall plants, and dual-scale automata cannot describe the organ growth state, thus, it is not fully applicable to the reconstruction of wheat plant morphology. In terms of the organ morphological modeling based on process, Mengjun, et al. described leaf vein curve with leaf specific weight, leaf inclination angle and leaf length, they could accurately describe the curl and distortion of wheat leaves in combination with the leaf shape and the geometric modeling of leaf edge; Wu Yanlian constructed the geometric model based on the characteristic parameters of organ morphology, including leaf, stalk and spike[5-6], which could dynamically describe the formation process of organ. In terms of the research on wheat three-dimensional visualization system, Chen Guoqing et al. proposed wheat three-dimensional visualization technical framework based on growth model[7], but the structural coupling of morphological model, growth model and visualization model was not taken into consideration. In addition, the structural storage of wheat plant topological structure and organ morphology characteristic data has not been reported.

On the basis of referring to the existing research findings and the observation and analysis on morphological structures of wheat plant, the concepts of macrostate, substate and microstate are put forward, the wheat growth mechanism model is established, and thus the formalized description of wheat morphogenesis process is realized. Through the analysis on the branch structure of wheat plant, the wheat morphological data model based on axis structure is proposed to realize the structural storage of plant topological structure and organ morphological feature data. On this basis, according to the thought of "growth model - morphological feature model - geometric modeling - display model", the visualization framework of wheat morphology is designed. On the VC++ platform, the virtual wheat growth system is built with OpenGL to realize the three-dimensional visualization of the morphological changes of organ and individual plant of wheat in the whole growth period.

2 The Technical Framework of Wheat Form Visualization

To accurately reconstruct wheat three-dimensional morphology, the technical framework of morphological visualization of wheat is designed by following the thought of "growth model - morphological feature model - geometric modeling - display model". The framework consists of virtual environment, growth model base, the model base of organ morphological characteristics, growth engine, visual engine, and wheat morphological data model and other components, as shown in Fig.1. 1) The virtual environment mainly includes weather data, soil information, variety data and cultivation management data. 2) Wheat-Grow is adopted for wheat growth model, and the system mainly uses the output growing degree days, leaf area index, nutrients, water and other influencing factors[8-11]. 3) Organ morphology characteristic parameter model is mainly composed of 4 parts, morphology characteristic parameter models of leaf, stalk, sheath and wheat head[6,12-13]. 4) The growth engine is made up of macrostate trigger, blade element trigger, growth engine drive, and branching (tillering) trigger and organ extension trigger. 5) Visualization engine is composed of engine drive, organ geometric modeling model and visualization model. 6) Wheat morphological data object is used to store plant topological structure and organ morphological characteristic data.

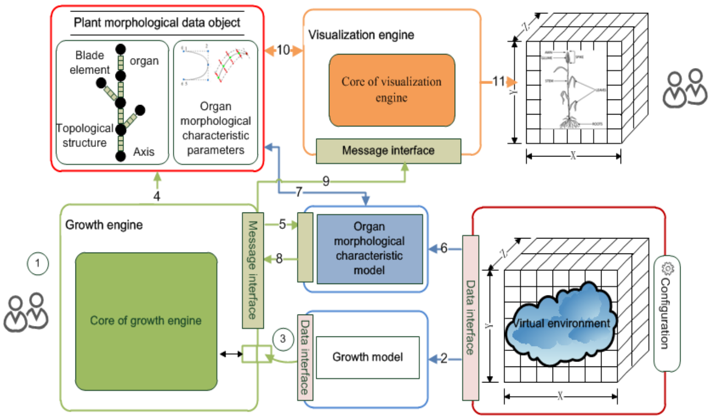

Fig.1. Technical framework of morphological visualization of wheat

Driven by the growth engine, the system invokes the growth model and morphological characteristic model of organ, calculates the physiological age of the wheat according to the virtual environment data, and then saves the plant topological structure at the physiological age and the related morphological characteristic parameters of leaves, stalks, nodes and spikes into the wheat morphological data model. The visualization engine receives the visual message sent by the growth engine, conducts precise geometric modeling of the organ according to the wheat morphological data model and splices the organs according to the topological structure of the organ to form an individual so as to realize the demonstration of three-dimensional configuration and visual computing function of wheat organs and individuals.

3 Wheat Growth Mechanism Model

Wheat growth mechanism model is composed of macro automata, child automata and micro automata.

The growth process of wheat is a unidirectional and irreversible evolutionary process, which passes through a number of distinct physiological stages, namely growth elements. In the model, macro-state represents the growth unit. Blade element, the meristematic unit of plant, is represented by sub-state. Since the growth unit is composed of blade elements, macro-state is constituted by sub-states, moreover, the blade elements in the same growth unit are in the same physiological stage. Changes of blade elements are embodied by the meristematic organs forming blade elements, and macro-state represents the growth state of the meristematic organs making up of blade elements.

According to the analysis mentioned above, the topological structure of wheat is generated by the growth mechanism model of wheat through the combination of macro-state, sub-state and micro-state and cycle simulation of growth process of wheat. In the system, the growth mechanism model is realized by the growth engine.

A. Macro Automata

Macro automata could represent the state transition among the growth units of wheat. It is defined as a hexahydric group: AP ::= $<Q_p, \pi_p, S_{GU}, C_p, \delta_p, F_p>$. Where, Q_p is the set of the finite state of macro automata, πp is the initial probability vector$(\pi_{pj})_j = (p(Q_{pi} = j))_j$; S_{GU} is the clock cycle that is needed for the growth of a growth unit; C_p is the time of macro-state circulation; $\delta_p \subseteq Q_p \times Q_p$ is the transition condition between states; Fp is the termination condition. The parameters in the automata are determined with the aforementioned wheat growth model in the system.

B. Child Automata

Child automata could express the state transition relationship among blade elements within a growth unit. Blade elements of wheat are classified as ml type and mt type; the former is composed of leaf, sheath and internode and the latter is constituted by spike and internodes under spike.

Child automata are defined as a hexahydric group, including AC::= $< Q_c, \pi_c, S_{ME}, C_c, \delta_c$ and $F_c>$. Q_c indicates the set of finite state of child automata and πc is defined as a vector of initial probability $(\pi_{cj})_j = (p(Q_{ci} = j))_j$. S_{ME} is the clock cycle during which a blade element outgrows. Cc expresses the cycling times of child automata. $\delta_c \subseteq Q_c \times Q_c$ indicates transition conditions between states and F_c is the termination condition. Parameters of child automata could be determined by phyllochron and growth model.

As wheat grows in cluster with a main stem and several lateral stems (tillering), 2 types of mechanisms need to be introduced in order to reflect wheat morphogenesis truthfully. 1) One is branching (tillering) mechanism which could decide time, quantity and disappearance of tillering and effects of external environment on tillering. A great number of studies have been carried out on this aspect[14-16]. 2) The other is synchronous mechanism. Lateral axis of wheat (tillering) has synchronous growth relation with its parent axis and its physiological age is the same to that of parent axis. However, the number of its meristematic units can not be greater than that of its parent axis. Therefore, when parent axis reaches a certain physiological stage, its lateral axis will also reach synchronously.

C. Micro Automata

Micro automata show transition relationship between specific states of organs within the blade element and are defined as a hexahydric group, including AM::= < Q_m, π_m , S_{OG} , C_m , δ_m and F_m>. Q_m indicates the set of finite state of micro automata and πm is defined as a vector of initial probability (π_{mj}) $_j$ = (p (Q_{mi} = j))$_j$. S_{OG} is a clock cycle in which the micro automata could change. $\delta_m \subseteq Q_m \times Q_m$ indicates transition conditions between states and F_m is the termination condition. Micro automata could be decided by rule of synchronous growth of wheat organs.

4 Plant Morphological Data Model of Wheat Based on Axis Structure

Plant morphology of wheat is manifested as branch structure composed of axes with the main axis and lateral axes of all levels included (tillering). Essence of plant morphological description of wheat is to reveal the following aspects: 1) Branch network, namely axis information, such as branch numbers of axis (tillering), blade element number, organ set, arraying order, etc.. Logical relation between axes and morphological description are also included, such as mapping relationship between branching (tillering) and parent axis, angles between axes, etc.. 2) Morphological characteristics of organs, such as length and width of leaf organ, angle between stem and leaf, length and thickness of internode organ, etc.. On this basis, plant morphological data model of wheat is constituted by set of axis objects, axis objects and organ objects, which describes relationship among them and morphological characteristics of organs from three aspects of axis, blade element and organ.

A. Set of Axis Objects

Set of axis objects is showed in Fig.2. As elements of a set, axis objects of all levels are ordered according to their occurrence time.

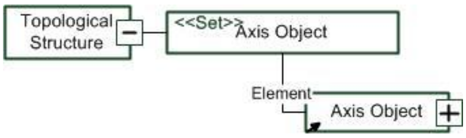

Fig.2. Set of axis objects

B. Axis Object

Structure of axis object is shown in Fig.3. 1) Identity of axis object is its key which reflects logical relations between axes. 2) Branching (tillering) number indicates number of branches in an axis. 3) Blade element number indicates number of blade elements in an axis. 4) Angle of parent axis shows the angle between an axis and its parent axis. 5) Leaf object set is the set of leaf organs constituting the current axis and its elements are leaf objects. 6) Sheath set is the set of sheath organs constituting the current axis and its elements are sheath objects. 7) Internode object set is the set of internode organs constituting the current axis and its elements are internode objects. 8) As to spike object, axis which could grow into a spike only has one spike organ.

In actual application of this model, organs constituting the blade elements could be added according to practical requirements. Morphological characteristic data of every organ object are recorded, which is not described in detail here.

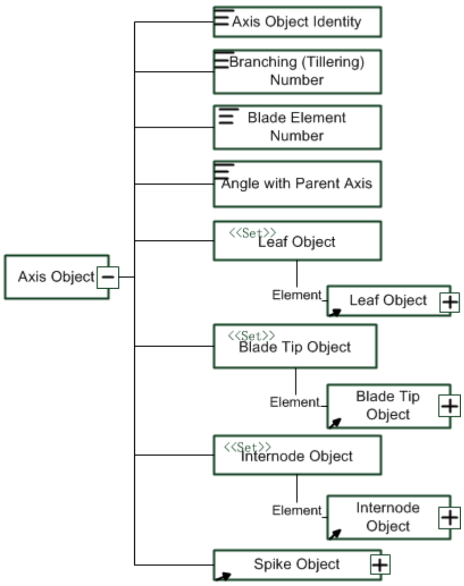

Fig.3. Axis object

5 Geometric Modeling of Wheat Organ

A. Geometric Modeling of leaf

Wheat leaf is constituted by blade and sheath. Sheath is under leaf and it is in an open cylindrical shape, surrounding the internode completely. NURBS surface modeling is applied to both sheath and blade in this study. Based on length and width of leaf, angle between stem and leaf, sheath length and other parameters output by organ morphological characteristic model mentioned above, control points of NURBS surface are determined. Control points of blade are included in 5 rows and 7 lines. Control points of the 4th column of every row are decided by leaf curve, other control points are on two sides of control points in 4th row when leaf is unfolded and the distance between two points is decided by leaf width. Geometric modeling of untwisted blade is shown in Fig.4.

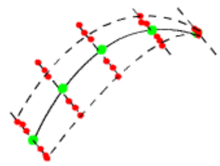

Fig.4. Geometric schematic diagram of untwisted blade

Twisted modeling of blade could be regarded as rotating the center-top part of blade around curve of leaf vein under the condition of unchanged vein curve. In terms of NURBS surface, it is manifested as rotating control points in 2nd and 3rd rows on blade around curve of leaf vein. As shown in Fig.5, l1, l2, l3 and l4 are lines connected by the control points in last 4 rows (control points in 5th row are all at the highest point of blade) and p1, p2, p3, p4 and p5 are 5 control points in curve of leaf vein. Through rotating 14 and 13 around tangent line of curve of leaf vein, twisted modeling could be achieved, namely, rotating 14 around the vector which passes point p4 and is parallel to p3p5 with an angle of ro and rotating 13 around vector which passes p3 and is parallel to p2p4 with an angle of ro. Twisting angle of r is within 0-180^{o}.

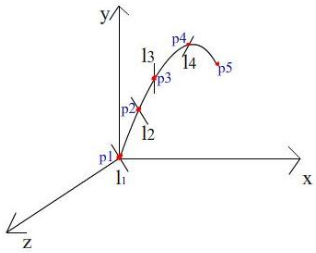

Fig.5. Geometric schematic diagram of twisted blade

Sheath of wheat is in an open cylindrical shape. Its modeling is mainly determined by radius R and height H. Control points are set to be included in 5 rows and each row has 7 control points. The first row is set to be a square with a side length of 2 x R which is defined as a circle with a radius of R. The x and z coordinates of control points in row 2, 3 and 4 are equal to those of row 1 and y coordinate has an equidistance rising. The y coordinate of control points in row 5 increases with the same space and x and z coordinates form into an open square, thus defining an open circle, as shown in Fig.6.

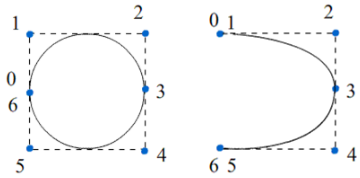

Fig.6. Geometric schematic diagram of sheath.

In order to ensure smooth connection between blade and sheath, y coordinate of control points of blade in first row could be set to be equal to that of control points in the highest part of sheath. Thus, control points in the 10 rows and 7 columns could form a NURBS surface to simulate the modeling of whole leaf, as shown in Fig.7.

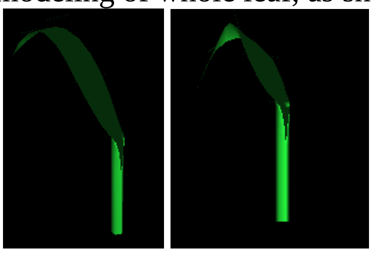

Fig.7. Morphological visualization of blade and sheath of wheat

B. Geometric Modeling of Internode

Wheat internode is manifested as a cylinder which grows to be thick and long gradually during the growth process and this is simulated by cylinder in quadric surface. Based on internode length and thickness output by morphological characteristic model of aforementioned organ, length and diameter of cylinder are determined.

C. Geometric Modeling of Wheat Spike

Structure of spike is relatively complex and could be divided into grain, axis, peduncle and awn. Therefore, method of combining several basic graphics was adopted to construct the three-dimensional geometric model of spike. Axis and pedunde of spike were modeled by cylinder in quadric surface. For species which had awn, model construction of awn adopted cylinder and ellipsoid was used to construct grain model. Visualization effects of spike are shown in Fig.8.

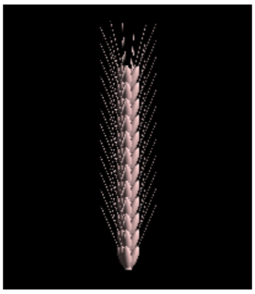

Fig.8. Morphological visualization of spike of wheat

6 Example Analysis and System Implementation

Based on the technical frame of wheat morphological visualization technology, virtual growth system of wheat was developed using VC + + and OpenGL. With the variety of "Yumai 34" used as the test materials, morphological characteristic parameters of "Yumai 34" were extracted based on meteorological data, soil characteristics, variety parameters, cultivation measures, etc. during wheat growth in Science and Educational Garden of Henan Agricultural University in 2008 and 2009. With variety parameters and model parameters extracted, plant topological structure and morphological characteristic parameters of all organs were generated using virtual wheat growth system. Three-dimensional morphology of all organs was drawn and three-dimensional morphological reconstruction of wheat individual was achieved, as shown in Fig.9.

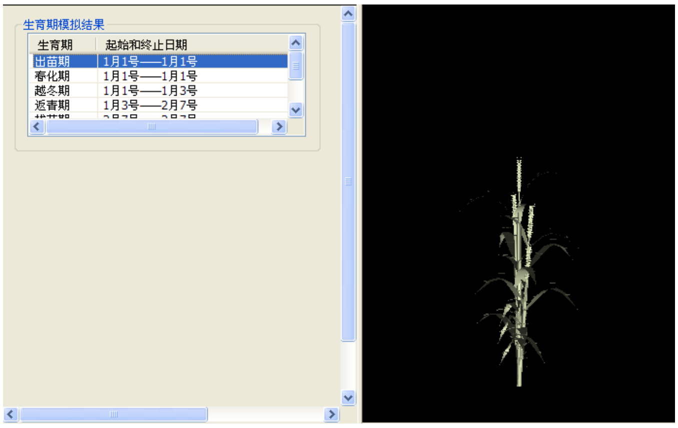

Fig.9. Interface of virtual wheat growth system

7 Conclusions

1) Following the thought of "growth model-morphological characteristic model- geometric modeling-visualization model", technical frame of morphological visualization of wheat was put forward in this study based on growth automata model of wheat, plant morphological data model and geometric modeling of organ. This frame combined the morphological model, growth model and visualization model organically. Based on the technical frame, virtual wheat growth system was established which could achieve three-dimensional visualization of wheat plant organ and morphological change in the full growth period of an individual.

2) Concepts of macro state, child state and micro state were put forward in this study from the perspective of botany and wheat growth automata model was constructed. Through introducing organ growth state, this method could reflect changes of blade element during growth precisely, which overcame the deficiency of dual-scale automata in this aspect. Besides, growth mechanism of wheat was also considered in this model and it combined with the agricultural knowledge effectively, facilitating simulation of wheat morphological process. This model had certain universality and could offer ideas and methods for studies on morphology and structure of other cereal crops.

3) Plant morphological data model of wheat based on the axis structure was put forward in this study and this achieved structural storage of topological structure of wheat plant and morphological characteristic data of organ. Combination of all organs could be

controlled conveniently and effectively using this model and virtual display of the wheat individual was achieved. This method was also applicable to structured storage of morphological data of other cereal crops.

4) This study did not involve the crop root. Therefore, further studies should be carried out on how to construct the morphological model of crop root so as to achieve the complete visualization of crop organ, individual and population.

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