

Geometry Modeling for Cotton Leaf Based on NURBS

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Abstract: - Digitalization of agriculture bring controllable industrial production and computer-aided design ideas into agriculture, NURBS curves and surfaces is described freedom of widely popular technology, CAD systems are widely used. Method can be easily applied to generate curves, surfaces with NURBS. In this paper, we have developed model of cotton organs using NURBS surface, present a introduction of Topological Structures on virtual plant from our personal perspective and simulated a 3-D growing of cotton with OpenGL and VC++ 6.0. briefly introduce method of simulating cotton organ based on NURBS and from our personal perspective present a introduction of Topological Structures on virtual plant. Based on VC++6.0 and OpenGL, methods of establishing models of main cotton organ using techniques of computer graphics are presented and realistic results have been achieved. Burls of stem and fruit branches are simulated by octahedronlike prism. Other organs are built based on NURBS. These organs are: bell, caulis leaf, fruit branch leaf, Petal, bract. Using NURBS we don' t need to obtain an abundance of accurate data and bother with regression equation by contrast with three-dimensional digital. Topological Structures of cotton is represented by C++ class: stem class and fruit branch class.

Key-Words: - NURBS, OpenGL, C++, Cotton, Topological structures

1 Introduction

The digitize of agricultural production and industrial control the thinking of the introduction of computer-aided design of agricultural, NURBS method is described in free-form curve and surface technology is widely popular in the CAD system has been widely used. Application method NURBS curve can be easily generated curve and surface.

Geometric modeling has already become an important tool for a variety of applications in many fields such as industrial design and manufacture, electrical and mechanical engineering, plant, etc. As a result, physical objects have widely been replaced by computer models.

The purpose of computer modeling is to construct a simple but reflects the real physical world use abstract mathematical description model, to simulate the occurrence of the subjects of research, development process, in order to explain the phenomenon, revealing the mechanism and found that the laws provide a useful tool to predict the future. Plant-targeted form of computer models

of a variety of categories, the classification of certain models or multi-meaning ambiguity exists in nature. Discussion of this issue will help us on the purpose of the model, the understanding of content.

Traditional study of botany and agricultural ways and means is a single discipline, experience, style, characterization of the model, information science, computer science knowledge, the introduction of changes in the traditional areas for new opportunities.

In recent years, with the rapid development of information technology, for the study of plant morphology and structure of the data collection methods such as three-dimensional digital technology level of computer hardware has been able to meet the demand needed to build a model of visualization technology, object-oriented programming methods is widely used. From botany, agronomy, ecology, mathematics, computer graphics and many other subjects and with the rapid development of the virtual plant model, it has the potential to meet such demand.

Modeling Plant Growth is to plant as the research object, but through a simple structure to reflect the real physical world of abstract mathematical description of the plant model to simulate the occurrence of the object being studied, the development process, in order to explain the phenomenon, revealing the mechanism and found that laws provide a useful tool for prediction. This research work is also known as a "virtual plant".

Plant growth and development in computer simulation and visualization can be traced back to 1962, Ulam applied cellular automata to simulation of the branching types of growth. Cohen then provided a space in continuous operation of more realistic model. In 1968 a biologist Lindenmayer proposed L-systems as a form of plant model system, the general tree framework, introduced the first computer model of the structure. Since then, the plant model was to become an active area of interdisciplinary research, led to biologists, mathematicians, computer scientists interested in this field.

A virtual plant is generated from a software model which consists of explicit rules for structural dynamics [1]. Virtual plants have found their applications in research, education and many other fields.

Computer models of plant structure and development can be divided into empirical or causal, Thornley and Johnson have described authoritatively the distinction between these two classes [2].

Advances in hardware and 3-D graphics environments results in significant improvements in performance and decreasing cost of personal computers, and makes it possible to run virtual plant software on personal computers and give more scientists access to virtual plants. Tools, such as 3-D digitizer, computer visual, are becoming available to obtain 3-D information.

Measurements in the field have been developed to describe the geometric of plants in 3D, and very realistic 3D representations have been obtained. Organs are approximated by a set of triangles [3], Bicubic Bézier patch [4], Axial Deformations [5] and etc.

In this paper, Main research contents are as follows: in VC++6.0 environments, the combination of OpenGL libraries, mainly for cotton dicotyledons three-dimensional modeling of organ shape, texture rendering, the simulation of dynamic growth of cotton. Shoot organs of cotton fields

based on images and measured data as a reference to create a virtual geometric model of cotton, as well as growth parameters.

A convenient and realistic way of simulating cotton growth is developed. NURBS surface organ model of part of the establishment of cotton, combined with C++ object-oriented technology, to achieve visualization of cotton growth. In order to simulate the size of the organ can be measured with the field data changes, given the shape of an organ simulation normalized solution to the problems. We have described model of cotton organs using NURBS surface and some problems in section 2, present an introduction of Topological Structures on virtual plant from personal perspective and simulated 3D cotton growth with OpenGL and VC++ 6.0 in section 3.

2 Modeling and simulation of the cotton organ

The purpose of computer modeling is to construct a simple but reflects the real physical world to describe abstract mathematical object model to simulate the occurrence of the object being studied, the development process, in order to explain the phenomenon, revealing the mechanism and found that the law, to predict the future as a useful tool.

A geometric model of embedding the projective 3D space in a Euclidean four-dimensional (4D) space (E^4) can be used to define NURBS surfaces. Points in E^4 are of the form $[x,y,z,w]^T$. Points in 3D space $[x,y,z]^T$ can be embedded in E^4 as $[x,y,z,1]^T$, i.e. the hyperplane $w = 1$ is considered a copy of 3D space.

2.1 NURBS

NURBS, Non-Uniform Rational B-Splines, are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic free-form surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process from illustration and animation to manufacturing.

NURBS geometry has five important qualities that make it an ideal choice for computer-aided modeling.

(1) There are several industry standard ways to exchange NURBS geometry. This means that customers can and should expect to be able to move

their valuable geometric models between various modeling, rendering, animation, and engineering analysis programs. They can store geometric information in a way that will be usable 20 years from now.

(2) NURBS have a precise and well-known definition. The mathematics and computer science of NURBS geometry is taught in most major universities. This means that specialty software vendors, engineering teams, industrial design firms, and animation houses that need to create custom software applications, can find trained programmers who are able to work with NURBS geometry.

(3) NURBS can accurately represent both standard geometric objects like lines, circles, ellipses, spheres, and tori, and free-form geometry like car bodies and human bodies.

(4) The amount of information required for a NURBS representation of a piece of geometry is much smaller than the amount of information required by common faceted approximations.

(5) The NURBS evaluation rule, discussed below, can be implemented on a computer in a way that is both efficient and accurate.

A NURBS curve is defined by four kind of things: degree, control points, knots, and an evaluation rule. The control points are a list of at least degree+1 points.

$$p(u, v) = \frac{\sum_{i=0}^m \sum_{j=0}^n \omega_{i,j} d_{i,j} N_{i,k}(u) N_{j,l}(v)}{\sum_{i=0}^m \sum_{j=0}^n \omega_{i,j} N_{i,k}(u) N_{j,l}(v)}$$

2.2 Cotton organ modeling with NURBS

Primary cotton organ includes fruit-bearing branch of cotton boll, bract, the main stems and leaves, fruits and leaves, cotyledons, petals. Cotton belongs to Malvaceae, which is a dicotyledonous plant, its seed embryo has two cotyledons, main stem round, two kinds of branching nutritious branches and fruit-bearing branch. Leafy shoot also known as the vegetative shoot, similar to its form and main stem is a single-axis-type branch. Fruit branch is located on leafy shoot is co-axis branches. Fruiting branches was tortuous branch-like, with the main stem of the angle between the large, almost at right angles to the leaves around right health.

Using geometric shapes providing by OpenGL to build eight prism surfaces to model Fruit branch,

the rest of the bells, leaves, petals are using NURBS surface modeling, using OpenGL's NURBS interface.

The use of NURBS modeling major organs of the cotton, such as fruit, bell, the main stems and leaves, fruits and branches, petal, bract, Compared with digital three-dimensional methods, save the need for a large number of accurate data for measuring and fitting of mathematical expression.

Each leaf by the formation of a NURBS surface, each NURBS surface control points by the three rows, each row the number of control points based on a variety of leaves to determine the shape of the edge. u, v the direction of the degree is 3 and 2 respectively, nodes are uniform vector of the node.

2.2.1 Cotton leaves modeling

It is difficult to express Cotton leaves edge use smooth the curve. According to the number of lobes, some control points repeated in each control point row. For each of the control points need to repeat the number of repeated degree consistent with the direction.

Figure 1 is control points on source cotton leaf images. In our NURBS model, all weights are equal to 1, the degrees in the u- and v-directions are 3 and 2 mostly.

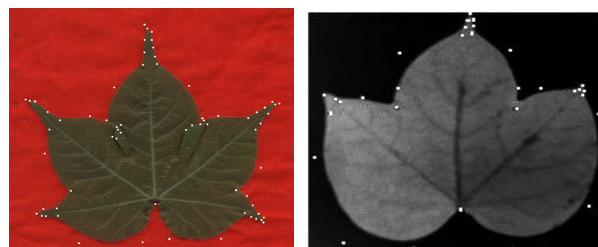


Figure1: Source Image with u- directions Control Points. (a) Cotton stem leaf, (b) cotton fruit branch leaf

Multiple knots may help to generate desirable results, the first (resp, last) n+1 knots are equal to 0 (resp, 1), other knots are be uniformly spaced.

In order to force a NURBS surface to pass a control point, some adjacent control points in cotton-leaf model are made identical. Figure2, Figure 3 illustrates the results.

We make the NURBS surface to pass some control points, so the normalization problem can be as simple as computing the distance between pairs of such points, the distance can stand for length or width or other geometry parameter in 2D.



Figure 2: Source image, NURBS surface, textured surface of bract

2.2.2 Control point, the texture coordinates to obtain

Control points were accessed by manually. Some control points repeated in each control point row. For each of the control points need to repeat the number of repeated degree consistent with the direction.



Figure 3: NURBS surface of petal

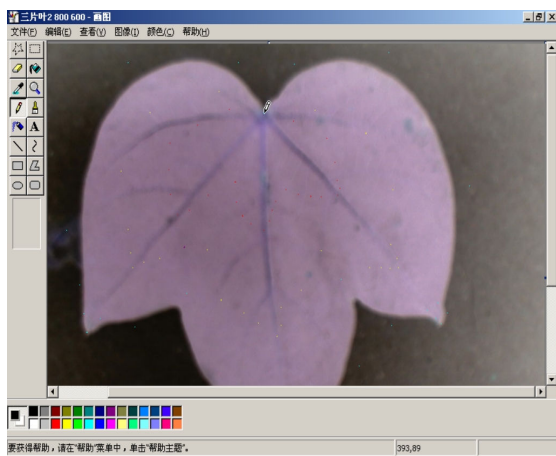


Figure 4: Acquisition of control points

See Fig 4, Petiole at the Windows Paintbrush location coordinates (393,89), other control-point method similar to the (X, Y).

In Fig 5, the black part of the image is to expand, the size of original image is 800×600 , image size is not a power of 2, expanded for the 1024×1024 . Digital camera take images of cotton organ size is 800×600 , in order to be able to achieve texture mapping under OpenGL, the application that comes with drawing tools for Windows systems, the picture size to be changed 1024×1024 , and then reduce into a 256×256 .

Since image size is to change 1024×1024 , so in order to facilitate the calculation of texture coordinates values are approximate $X/1000$, rather than $X/1024$.

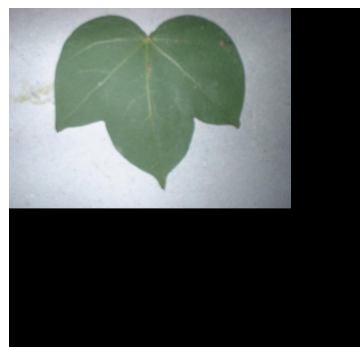


Figure 5: Modify the texture image in size 1024×1024

2.2.3 Cotton boll modeling

Cotton Boll uses two kinds of modeling methods: One is to use OpenGL to provide a simple geometry, and the other is a NURBS modeling method.

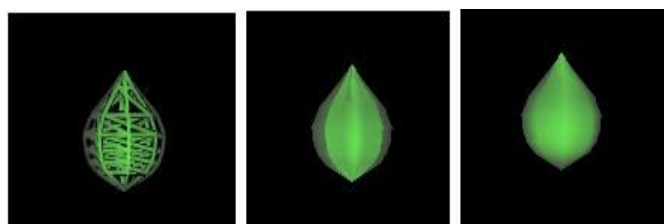


Figure 6: A simple boll GL_LINE, GL_FILL modelling approach

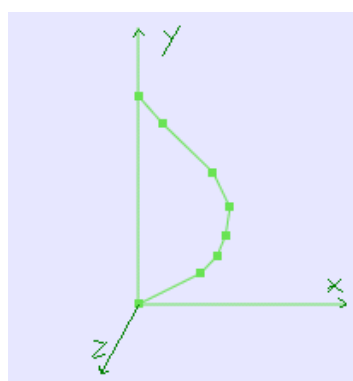


Figure 7: 8 control points of simple boll in XOY plane

In a light situation, need to calculate the normal vector of cotton boll for every surface. Even from this eight-point edge into seven segments namely, Normal vector can be calculated according to the definition of mathematical, the vertical line segments in which the vector. Positive and negative

vectors can be seen from the figure, mainly by the need to calculate the two situations, when the segment at both ends of the coordinates of points: a point x, y values are less than one point, the vector x, y, respectively positive and negative; a point x is less than (or greater than) to another point x value, while y is greater than (or less) to another point, the vector x, y respectively, positive, positive. The first one-point normal vector is (0,1,0), the origin at point the normal vector of origin coordinates is (0, -1,0).

Side profile around the Y axis week, taking four groups in the coordinate axis, coordinate axis to take the four groups, a total of eight sets of edges as a bell, in accordance with Figure 6 shown in the figure on the left of the GL_TRIANGLE_STRIP connected. Reference XOY plane eight control points coordinates and edges of the normal vector, you can easily calculate the other seven groups of control points and edges of the normal vector. Figure 7 with reference to the cotton boll picture by taking the side profile, XOY plane diagram of the control point.

(1) The selection of control points

First determine control points of cotton Boll side profile, the reference image selected Boll six control points Boll depicts the , as the direction of the control points v, and then 360-degree rotation around the y-axis, take 8 groups control points with same interval.

In order to draw a closed surface, together with the initial coincidence of the 3 groups of control points, a total of 11 groups, u and v the direction of control of 11 and 6 points respectively. Figure 8 is source image and NURBS surface of bell, the degrees in the u- and v-directions are 3 and 3.

(2) Node vector

u, v vector of nodes in both directions are more or less uniform vector, because of u, v the direction of the number of nodes because they can not just equal divide, so a small portion of the node and other nodes are not equal Distance.

(3) Curve number

u, v in both directions the number of degree of curve for 3. Thus the number of nodes was 11 +3 +1 and 6 +3 +1 or 15 and 10 respectively

```
GLfloat Lingknot [15]=
{0.0,0.07,0.14,0.21,0.28,0.35,0.42,0.49,0.56,0.6
3,0.70,0.77,0.84,0.91,1.0};
GLfloat Lingknotsix[10] =
{0.0,0.0,0.0,0.0,0.3,0.7,1.0,1.0,1.0,1.0};
GLUnurbsObj *LingNurb;
LingNurb= gluNewNurbsRenderer();
```

```
gluNurbsProperty(LingNurb, GLU_SAMPLING
_TOLERANCE, 2.0);
gluNurbsProperty(LingNurb, GLU_DISPLAY_
MODE, GLU_FILL);
gluBeginSurface(LingNurb);
gluNurbsSurface(LingNurb, 15, Lingknot, 10, Ling
knotsix, 6*3, 3, &Ling[0][0][0], 4, 4, GL_MAP2_VER
TEX_3);
gluEndSurface(LingNurb);
```



Figure 8: Source image with control points and NURBS surface of bell

2.2.4 Modeling of leaf and cotyledon

Figure 9 shows NURBS surface model of cotton leaf and cotyledon

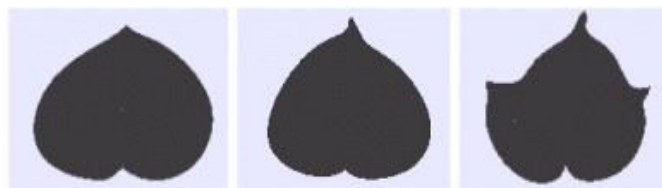


Figure 9: NURBS surface of part of Leaf on the cotton stem

2.2.5 Modeling of cotton bract

115 control points of cotton Bract edge is as Figure 10 below:

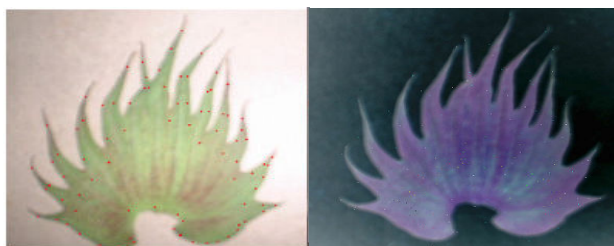


Figure 10: Fruitbranch model

The number of vector nodes is set as 115 and 119 respectively for u direction of control point, v direction of selected control points, the number of vector nodes is 3 and 2 respectively.

The regular arrangement of lateral organ is known as phyllotaxis. Phyllotaxis of euphylla and fruitbranch on main stem of cotton is $3/8$. Figure 11 depicts a euphyllas NURBS surface.

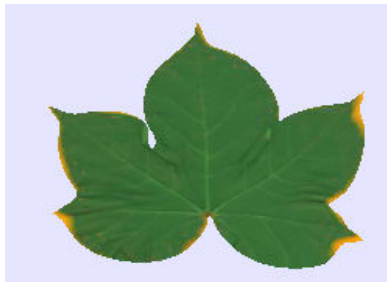


Figure 11: euphyllas NURBS surface

We use Paint program in WINDOWS system to obtain 2D coordinates values (X,Y) of control point.

Firstly, we get pixel coordinates values (X,Y) of some point that we want it to be the control point on the image, and multiply it by 0.001 or some other suitable value in order to make X and Y ranged from 0 to 1. Finally We need some transformations on the coordinates of the points.

By modifying Z value of control point we can get a NURBS surface in 3D, it is illustrated in figure 3 and 6.

3 Visualization of cotton growth

The notion of topological structure relies on the ideas of decomposing a plant into elementary constituents and describing their connections. Plant decomposition may a priori be either artificial or natural.

The topological structure of a plant is a subject object depending on the identification by an observer of the marks associated with constituents. A model of the topological structure of plants is an objective representation of the topological aspect of plant structures [6].

Plant modeling attracted the efforts of biologists, applied plant scientists, mathematicians, and computer scientists. Models on topological structure have been developed, such as Multi-scale Topological Structures, reference axis, dual-scale automation and all kinds of L-systems. There are some shortcomings of these approaches.

At present, we describe cotton topology and realize cotton growth by using Object-Oriented Programming.

3.1 The issue of dynamic growth texture

Taking into account the actual shooting leaves with a picture of the different periods of time and the need to build multiple models corresponding to the problem, the use of a texture image with the HSL (Hue, Saturation, Lightness) value adjustments to the process of growth largely reflects the changes in leaf color, fruit branches in Figure 12. 24 bit texture using the BMP files, image size is $256 * 256$.

Compared with the normal growth environment, cotton pests, such as in an organ will occur under the conditions of change, which will also require further improve, it can consider the use of control points x, y, z coordinates of the changes combine with texture mapping to achieve.

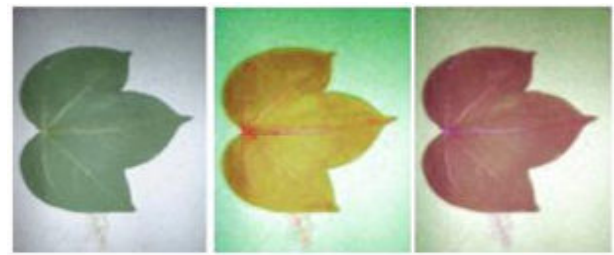


Figure 12: HSL value of texture picture adjustments

3.2 Cotton organ establishment with C++ Class

The combination of C++ class, we established main stem, branch, bud, flower, bell in the VC++6.0 environment, to achieve the dynamic growth of cotton. But Simulation of cotton is not currently considering the growth of vegetative tillers.

Cotton is mainly divided into the main stem and two major categories of fruit. Main stem of the members of the main categories are: main stem, Leaf, the main stem and leaf, petiole, fruit category. The membership of the fruit category is: fruit section of the fruit, bell, flower, bract, fruit branches, and petiole.

Various organs of the geometric model as the corresponding class member functions, growth in the process of geometric parameters of the corresponding data members of class, single organ not to be build class.

Stem class and fruit class has its own texture data respectively, set for static type for save storage space.

We define three classes: NURBSCotton class, mainstem class and fruitbranch class.

The NURBSCotton class has data member: mainstem class, and the mainstem class has data member: fruitbranch class.

The main class data members of mainstem class are: stem, cotyledon, euphylla, leaf stalk, the fruitbranch class. The main class data members of fruitbranch class are: burls,bell,petal,bract, leaf,leaf stalk.

Simulations of cotton organ with OpenGL are provided as member functions. Geometry parameters during cotton growth are provided as data members.

3.2.1 FruitBranch class

The following are main data members of class FruitBranch on geometry parameters during cotton growth :

```
braceAngel[7];
Stalkwidth[7];
StalkLength[7];
YScale_bract[7];
XScale_bract[7];
YScale_bell[7];
XScale_bell[7];
Scale_leaf[7];
....
branch_age;
burl_radius[7];
burl_length[7];
```

Figure 13 and Figure 14 are fruitbranch of different stages.

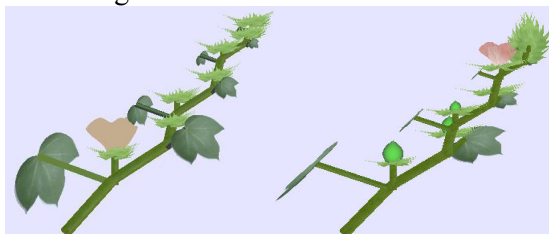


Figure 13: Petal on fruitbranch

Figure 11 illustrates the result of rendering main stem and leaf on different stages. Figure 12 is the result of Petal and bell on fruitbranch.

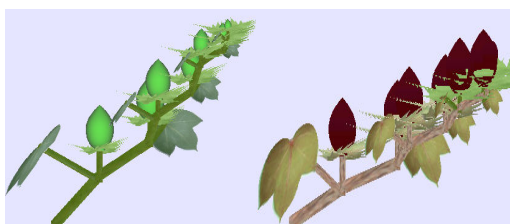


Figure 14: Petal and bell on fruitbranch

3.2.2 MainStem class

Figure 15 shows the effects view of mainstem and leaf, mainStem class data and function members are:

```
FruitBranch Branch[21];
GLfloat Leaf_Bing_Angel[25];
GLfloat LeafBing_stemAngel[25];
GLfloat Leaf_yScale[25];
GLfloat Leaf_XScale[25];
GLfloat Leaf_Bingwidth[25];
GLfloat Leaf_Binglength[25];
int BurlAge[25];
double m_branch_position[22];
double m_burl_radius[25];
int m_age;
int m_StemNum;
double m_burl_length[25];
staticBYTE Image_cotyledon_green[256][256][3];
.....
Static void SetTextureImage(CString
FilePath,CString ReplaceName);
void SetTexture(BYTE Image[256][256][3]);
void GrowByAge();
void Show(TextureSet_Bmp &,GLfloat
XPos,GLfloat YPos,GLfloat ZPos);
```

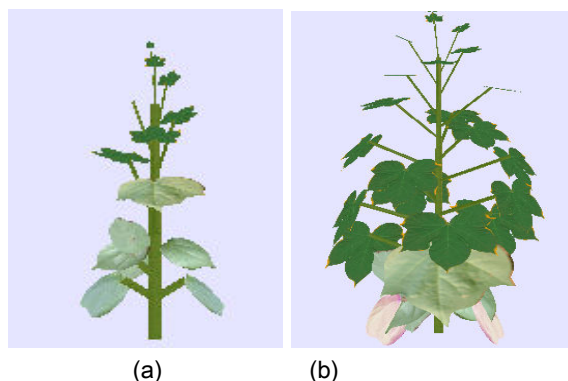


Figure 15: (a),(b) main stem and leaf on different stages

3.2.3 Cotton class

Data members and function of cotton class is less, the majority of functional to be implemented in the main stem. Figure 16 shows different from the growth period of cotton.

Class NurbsCotton data and function have mainly:

```
int cotton_age;
MainStem stem;
void LoadTextureFile();
void growAge();
void Show(GLfloat XPos, GLfloat YPos, GLfloat
ZPos);
```

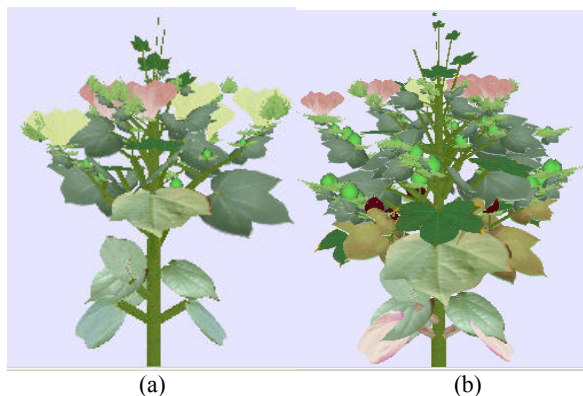


Figure 16: (a) , (b) virtual cotton at different growth stages

3.2.4 OpenGL texture mapping during cotton growth

Texture mapping, Load RGB image data from BMP files, source image file size is 256×256.

It is necessary for all the objects of fruitbranch class to access a global object. In these cases, a class static data member provides a better solution. It is simply more efficient to provide one global object used by all the objects of the particular class type than to have each class object maintain its own separate data member.

A static data member acts as a global object that belongs to its class type. Unlike other data members where each class object has its own copy, there is only one copy of a static data member per fruitbranch class type.

Source image file size smaller than 256×256 should be considered in future work.

We adjust HSL values on image file, so it can reflect texture at different stages during growth.

4 Cotton Data Processing

4.1 Geometric model of cotton organ normalized

In order to achieve the visualization of measure cotton data growth with the combination of cotton, the geometric model of the cotton organ size is need normalized.

Main stem, fruit, the section length, width to be describe by the long prism, the radius of circle of prism bottom respectively.

All kinds of leaves: in the establishment of NURBS surface model, the surface through the leaf lobes of a few control points, as well as the control point of leafstalk, so the length of the leaves and the width between the tip through these control points

for the length between normalized, the actual measurement data through the length of the leaf between the lobes to be measured.

Boll: Similar to the length of the leaves, through length between the control points and the top and bell to be described, the side of boll did not pass the control points, take difference X coordinate's value between the top and side control widest point.

Petals: petals surface through the corners at the four control points, which generally carried out using the four-point normalized.

4.2 Cotton growth data

There are 20-25 main stem sections, around 1m high. Seedling growth generally slow to accelerate, mature bud significantly accelerated flowering up to 50% of the ultimate high, after the full flowering stage the growth rate slowed down and gradually stop. On seedling growth of main stem 0.5-0.8cm, bud stage 1-1.5cm, mature bud Phase 2-2.5cm, boll full bloom period of 1-1.5cm, opening of a boll period to stop the growth of main stem.

Fig 17 shows the cotton program interface, the main stem and the growth of main stems and leaves.

This can be seen from the figure 15, the surface texture and image of leaves are not entirely coincide. Therefore, after establishment of leaves NURBS surfaces, you need to partial adjustment of the texture coordinates



Figure 17: Cotton Program Interface

5 Conclusion and Discussion

NURBS surface methodology used to establish a geometric model of the organ of cotton, texture rendering, in VC++6.0 under the combination of OpenGL to achieve the cotton growth simulation visualization, made a very realistic effect, compare with the three-dimensional Digital methods, saving a great deal of accurate measurement data and mathematical expression of the fitting work.

At present, leaves, petals modeling of these organs, first of all to establish its NURBS surface XOY plane, and then by modifying a small part of the Z coordinates of control points to get the three-dimensional surface.

In the description of topology, the cotton stems and fruit-based decomposition of two C++ Class to describe, the rest of the use of member functions to achieve.

About modeling on cotton fruit, this paper simplifies the results section for the cylindrical geometry. In order to more truly reflect the shape of fruit, we can consider using three-dimensional image reconstruction of the plant.

The main stem and leaves of cotton have five lobes, all lobes have their own characteristics, this article be used as a NURBS surface modeling to its 3-D space rather than the shape of the projector to a variety of surfaces can be easily resolved. On its surface is divided into a number of ways to connect and then the feasibility study needs to be further divided into paste texture and there is also need to be considered. May consider using the 3D software to build and then read into the program and so on. We can also considered by the parametric curve to control the method of free-form deformation of objects.

Virtual plants on your computer's performance also made the request. Variety of plant components in a virtual or simulated interaction with the surrounding environment, every step of the calculation of the volume is very large, if the realization of visualization, it will need to spend more computer time. To realize the truth of biology, virtual plants, the need for run-time in seconds rather than minutes, and now the computer's hardware and 3-D graphical environment to enable more researchers to carry out the virtual plants can begin to research and applications. Parallel processing computer for the progress of the performance of the virtual plant simulation will also play a significant improvement, because in reality many of the activities of plants are also parallel.

Real-time display of virtual plants also can be said to be occupied by the computer resources. Comply with the order to simulate the complexity of biological characteristics and botanical tree structure

will occupy a lot of computer resources. In order to reduce the occupation of computer-funded, literature [7] presents a subset of from the simplest structure, through the sub-structure of the reference to the method of formation of complex structures. As a result of the method in the structure of repeated only once, so not only can increase the complexity of the structure of the computing speed, and can reduce the amount of geometric information storage. The geometric information includes not only the simulation of plant growth cycle in all the structures, but also for each specific form of sub-structure.

Depending on the application, different degrees of realism may be sought.

The following problems still require improvement:

□(1) 3D models of cotton organs. Number of control points should be decreased in future work. We firstly build 2D NURBS surface models of cotton organs on XOY, and modify Z values of few control points, so it becomes 3D models in some way.

(2) Development of cotton organs. We have not applied integration of continuous and discrete aspects of development into one model, called differential L-systems [7], or Growth functions [8]. We have measured some data of cotton during growth, such as length of leaf, burl diameter of main stem and fruitbranch. In future, we will combine measured data with cotton models.

Virtual plant models are expected to have applications in broad sectors, including performing virtual experiment in different scales for agriculture research, constructing virtual farm for education, training and extension, landscape architecture design for parks, gardens and other open spaces in urban areas, and artificial landscapes for entertainment. The modeling methodology of virtual plants can be useful in different scales such as modeling the architecture of cells and its functions at micro-scale.

With the rapid enhancement in PC technology and decreasing price, virtual plant models will be available on personal computer in the near future. A combination of price and capability of computing is giving more botanists access to virtual plant models for education and agricultural extension purpose. Extending to the future, virtual farm will be constructed. Students or farmers can plant virtual crops and manage virtual fields on computers, observing crop growth from any angles or roaming in the virtual crop canopy to see how their plants will develop if alternative agronomic or practices are applied. Virtual plant models make farm

managers' access to the new technology of field management easier, more efficient.

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