3D COMPUTER SIMULATION FOR LIGNIFICATION OF ANCIENT CHINESE TIMBER BUILDINGS

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ABSTRACT A pioneer research work was carried out by investigators engaged in surveying and mapping for describing ancient Chinese timber buildings by 3D frame graphs with a computer. Users can know the structural layers and the assembly process of these buildings if the frame graphs are processed further with a computer model. This can be implemented by computer simulation technique. This technique display the raw data on the screen of a computer and interactively manage them by combining technologies from computer graphics and image processing, multi-media technology, artificial intelligence, highly parallel real-time computation technique and human behavior science. This paper presents the implementing procedure of lignification simulation for large-sized wooden buildings as well as 3D dynamic assembly of these buildings under the 3DS MAX environment. The results from computer simulation are also shown in the paper.

1 Introduction

The art of ancient Chinese architecture is the essence of the Chinese cultural heritages. It has important significance for studying and learning Chinese culture and civilization. It is of great difficulty, however, to learn the complicated structure of ancient Chinese architecture due to the lack of reference data because of the factors of time and natural or human-made disasters.

In the project of reconstruction of the Zhilian Nunnery, the Tang Dynasty Temple Reproduction in Hong Kong, the architectural supervisor of Wuhan Technical University of Surveying and Mapping reconstructs the sampled data of the building by using a 3D model with a computer, and uses it for quality checking and as the reference data for preserving the building forever. This will provide accurate, objective and detailed line and frame data of the building for studying, maintaining and reconstructing it in the future. It also provides a new method for protecting ancient cultural heritages. However, though the graphs of line and frame of the building are convenient for surveying and mapping, it is not for architects to study it profoundly. Computer simulation is a vivid research field developed in the 1980's. It combines several key techniques from computer graphics, multi-media technology, artificial intelligence, highly parallel real-time computation and human behavior science. Computer simulation displays data flow on a computer screen, so as to provide the end users a virtual realistic experience and a convenient way for observing and studying macro-world and micro-world which are impossible of direct observation due to various influences. If this technique is combined...
with virtual simulation technology, then it is convenient to common users to see the structure layers and interior feature of the building. This is also useful for archaic culture experts, ancient architects and construction engineers to locally or globally observe, analyze and study the building upon a computer. If the computer simulating re-occurrence procedure is coordinated with dynamic simulation and commentary, music, then the explanation of the characteristics of ancient Chinese architecture will be not only visual but also in an entertainment environment. This paper studies wood texture simulation and dynamically virtual simulation and provides the primary results.

After carefully learning the structure of ancient buildings, knowing the order and regulations for mounting a building, we employ AutoCAD12.0, 3DS MAX and OpenGL as the basic tools for the simulation process. A series of small programs have been developed to implement this study.

2 From 3D frame graphic to surface model

In the project of the reconstruction of the Zhilian Nunnery, all the data of the real timber components of this ancient building are measured and represented as line and frame graphs by a computer. In this way, the connection of different components can be described completely and it even can determine the connection quality between mortises and tenons directly from the screen of the computer. But it is not a stereo representation and is un-convenient for observation. In the following section, the surface model is used to replace 3D frame model based on the analysis of the latter.

2.1 3D frame model

An instance of this model is shown in Fig. 1, which is generated by AutoCAD12.0. The computer records the coordinate values of all the vertexes in the figure and the relationship table of the lines between two different vertexes. This model can provide scenograph of arbitrary direction of view, but it is not suitable to obtain section graph, intersection graph of two planes, blanking graph and profile graph. Therefore, this model can not satisfy the pre-requisite of stereo modeling completely.

2.2 Surface model

This model firstly uses the sealing parts encapsulated by edges of different components to define the surfaces of an object, then defines the object. The data structure of this model is to append an extra information table to the structure of 3D frame model. It can be used to process blanking graph, profile graph and so forth. The following little program is developed under AutoCAD 12.0 to compose a surface based on many vertexes:

```lisp
(defun c:plface (/ r1 t1 ss startPt)
  (savenv) ; saving currently state
  (setvar "osmode" 512)
  (initget 1)
  (setq t1 (getpoint "Select PLINE: ")) ; select point
  (cond
    ((eq (type tl)'LIST) (setq ss (getpl tl))
     (cond ((null ss) (princ " No Polyline found."))
           ((= (sslength ss) 0.) (princ " Entity is not a Polyline."))
           ((= (sslength ss) 0) (princ " No Polyline."))
           (if (eq (type pt) 'LIST) (grdraw p0 pt - 1 1)))))
  (progn
    (setvar "osmode" 1) ; endpoint
    (initget 1) (setq startPt ); getpoint
    (if (eq (type pt) 'LIST) (grdraw p0 pt - 1 1))
    (if (eq (type pt) 'LIST) (progn (setvar "osmode" 0)
                                (command pt)
                                (setq n (1+ n)))
     (setq loop nil)))
```

Fig. 1 Frame model of timber component
(command """)
(setq i 1) (repeat n
(command i)
(setq i (1+ i)))
(command """")
(resenv)) ; restore

A series of surfaces composed by the above program is shown in Fig. 2. These surfaces are easy to observe and can intuitively describe the relationship of components. This model is the foundation of lignification.

![Fig. 2. Surface model of timber components](image)

### 3 Simulation of lignification and moving control techniques

Because the ancient building was built of wood, lignification is one of its characteristics. In order to generate satisfactory and virtual realistic images of a timber building by the 3D computer simulation system, the surface material of each component besides the establishment of correct model needs simulating. Other components of the ancient building were connected by mortises and tenons. When mounting the ancient building, the order of mounting different components is vitally important and restricted by their shapes and physical characteristics. The position of each component is measured by surveying.

#### 3.1 Generating material texture

The main task of generating material texture is to determine the color, texture and light and shade pattern of the material. The color of a material can be divided into three categories: ambient—the color of the shading part of an object, diffuse—the color of an object under lighting, and specular—the color of an object under strong lighting.

Texture describes the natural characteristics of the surface of an object, which can be generated by a 2D random function \( f(u, v) \), where \( u \) is the width of the texture, \( v \) is the height of the texture. Let \( N(\mu, \sigma) \) denotes a normal distribution function, where \( \mu \) represents the mean value and \( \sigma \) represents the standard deviation. Its value relies on the type of the material. The method for generating \( f(u, v) \) is as follows:

\[
\begin{align*}
    f(u_{\min}, v_{\min}) &= f_1 = N(0, \sigma) \\
    f(u_{\min}, v_{\max}) &= f_2 = N(0, \sigma) \\
    f(u_{\max}, v_{\min}) &= f_3 = N(0, \sigma) \\
    f(u_{\max}, v_{\max}) &= f_4 = N(0, \sigma)
\end{align*}
\]

Therefore, the generation of a random function upon the interval of \([u_{\min}, u_{\max}] \times [v_{\min}, v_{\max}]\) can be decomposed to the generation of 4 random functions upon 4 sub-intervals derived from the segmentation of the whole interval into 4 parts, with the cut-off point on \((\cdots)\). A recursive process is applied by using the above mentioned algorithm until the detail of the generated texture is satisfactory enough. According to Eqs. (1) and (2), the standard deviation is multiplied by \(2^{-H}\) after each iteration (0 \(\leq\) \(H\) \(\leq\) 1). \(H\) is the so-called self-similar variable. If let \(H = 1\), then the standard deviation will be half of its original value after each segmentation, which will lead the generated random function to change significantly within a local area, so that rich in texture. If this 2D random function is added to a curved surface, then the texture on the surface is generated. Besides, the chartlet of texture
can be from a scanned image or generated by a graphic package \cite{2}.

3.2 Problems of application of texture chartlet

Texture chartlet is used frequently in the whole simulation process of lignification. If all the texture chartlets used look like the same in pattern but different in texture, then the surface generated by these chartlets will look like wallpaper. In order to solve this problem, the material texture needs to change randomly. Usually, large bitmap can be used. However, processing it requires much computation time and storing it needs more memory space. If different chartlets are merged with certain proportion or particular noises are added into chartlets, thus the problem can be solved effectively and operationally. The results are shown in Fig. 3 to Fig. 6.

![Fig. 3 Emulational picture of Dou-gong](image)

![Fig. 4 Emulational picture of Dou-gong layer](image)

![Fig. 5 Emulational picture of tower](image)

![Fig. 6 Emulational picture of bell Dou-gong layer](image)

3.3 Moving control techniques

All the graphs and images generated up to now are stationary. The core of our project is dynamic virtual simulation, so computer animation technique is a must. Though many techniques of animation can be considered, the key-frame-based method is adopted here.

The most popular computer animation technique is based on key-frame. The core of this technique is to fix the so-called key-frames, and then let 3DS MAX software system interpolate to generate those between key-frames. The $B$ spline function is used (Fig. 7).

![Fig. 7 Movie of key frame](image)
After the attribute values of key frame is given, they will be stored in a structure named curve node and will be controlled by the node. These curves are defined by the attribute data of the key frame, the speed of the animation then can be adjusted by the tangent of a curve.

Usually, the gradient of a curve indicates the speed of an object (Fig 8). Steep curve indicates high speed, and flat, low. Consequently, the horizontal curve indicates the ceasing object. Fig. 9 shows the pictures of build-up process of timber components.

![Fig. 8 Slope and speed of movement](image)

![Fig. 9 Movie of a series of Dou-gong](image)

### 4 Conclusion

Computer simulation is a hot research field in computer science. It provides a novel environment for people to explore macro-world and micro-world. It is also the superb stage of multi-media technology. However, to implement this technique perfectly, obstacles are on the way. Both speed and processing capacity of computer hardware are limited, and the price of high quality display equipment is also excessively expensive. On the other hand, expense of software development is also out of tolerance. Many works are still waiting for people to do.

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