Computer Graphics and Virtual Reality Research in NCTU

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Abstract

There is considerable research activity related to computer graphics and virtual reality within the National Chiao Tung University (NCTU), Hsinchu, Taiwan. In this article, we describe the history of computer graphics at NCTU and report on our current research topics and future works. Besides we also briefly outline the research works on computer graphics and virtual reality within universities in Taiwan.

1. Introduction

The computer graphics research group in NCTU was originated from 1988. It consists of four faculty members. The major research areas are global illumination, texture synthesis, animation, and virtual reality. In this article, we present part of our research works in these areas. The results of these research works are shown in the corresponding figures.

2. Illumination

Illumination is related to the lighting appearances of the objects. Radiosity provides a solution in solving the illumination problem. It has been studied in our laboratory. We introduce our research on radiosity in the following paragraphs.

The greatest challenges in radiosity are those of accuracy and efficiency. Up to now, especially in efficiency, there are many works devoted in the radiosity literature. But, there still has few work in discussing the accuracy of radiosity. Radiosity approaches can only produce approximate results, thereby accounting for why error exists in the solution. If the error can be estimated accurately, we can obtain more accurate solutions of radiosity. Therefore, reliable and accurate error estimations are crucial for radiosity. In our approaches, we make more accurate error estimations on radiosity and propose accurate radiosity algorithms to meet the user-specified error tolerance.

We propose an algorithm to enhance the accuracy of the hierarchical radiosity. The proposed approach particularly creates links on the hierarchy in a bottom-up fashion according to both a user-specified error tolerance and the minimum patch area. It differs from the original hierarchical method that creates the links in a top-down manner. In our approach, the upper-level patches have more accurate estimates of the kernel. More accurate error bounds can be obtained for the upper-level patches. These error bounds make the creation of links on the hierarchy more accurate. More accurate form factors can also be obtained for the upper-level patches. Thus, we enhance the accuracy of hierarchical radiosity.

Then we derive a tighter error bound on form factors as a subdivision criteria for the hierarchical radiosity algorithm. Such an error bound can reduce more unnecessary links and improve the performance of the hierarchical radiosity algorithm to meet a user-specified error tolerance. We also propose a weighted error metric in form-factor computation such that more efforts are automatically applied toward shadow boundaries. Evaluating form factors along shadow boundaries with a higher degree of precision would enhance the quality of human perception. Using the proposed tighter error bound on the weighted error metric, we not only improve the performance but also increase the accuracy of the hierarchical radiosity algorithm. The resulting image generated by our approach is shown in Figure 1.

Ray tracing is an important technique for the realistic image generation in computer graphics. However, ray tracing usually consumes high computation cost, this will be more noticeable for ray tracing parametric surfaces. A few algorithms have been developed to speed up the execution time of ray tracing parametric surfaces. Three main research directions are: (i) development of techniques that reduce the number of surfaces to be checked against each ray, (ii) development of efficient algorithms for calculating the ray-surface intersections, and (iii) development of efficient schemes to reduce the number of intersection points that need to be found. In this proposal, we propose a fast hybrid algorithm for ray tracing parametric surfaces. And for the third research direction, we introduce a general strategy to improve ray tracing parametric surfaces.

In our research, we propose a fast ray tracing algorithm for parametric surfaces and a general strategy for improving ray tracing parametric surfaces. The fast ray tracing algorithm is a combination of Bezier clipping and Newton's method. Bezier clipping is used to find the first intersection points and Newton's method with ray-to-ray coherence is used to find other intersection points. This combination achieves a significant improvement on tracing primary rays. To determine whether an intersection point found by Newton’s method, we introduce the back tracing technique.

Our general strategy is based on the

back tracing technique. The general process of our strategy is as follows. Given a traced ray and a surface, we first find an intersection point instead of finding all the intersection points. Then we use the back tracing technique to verify whether this point is the closest one. If this point is the closest one, the computation of finding other intersections can be eliminated. On improving the performance of any published algorithm, we apply this general process to find the closest intersection points instead of using the original method of their algorithm. The main advantage of our strategy is that the number of intersection points that need to be found to locate the closest intersection points can be reduced. Our strategy could introduce a significant improvement on accelerating the computations when the environments contain more high curvature surfaces. In addition, we also propose a general strategy to improve the performance of tracing secondary rays. The result is shown in Figure 2.

3. Texture Synthesis

In computer graphics, textures play an important role in adding the visual richness of objects and enhancing the realism of rendering results. The exertion of texturing can diminish the "shiny plastic" effects produced by using simple shading models and makes the objects apparently more realistic. A few works in texture synthesis at NCTU are described below:

(1) Fur Rendering

As to fur synthesis, there are enormous strands when we try to produce the furry surface in great details. Without suitable model representing the strand object, the synthesis process will take a long time and need huge data space. In order to overcome these problems and provide the flexibility, we take the concept of procedural texture to represent each strand of fur. That is, treat the fur as a series of line segments and let it grow out gradually from the scalp. On the other hand, instead of using a complicated shading model, a simplified shading model makes the overall synthesis process simple and efficient. This approach produces results fast and solve the memory-intensive problem, while still preserves the realistic image quality, as shown in Figure 3.

(2) Procedural Texture Synthesis for Curved Surface

Realistically synthesizing textures on curved surfaces is one of the most challenging problem in computer graphics. We use procedural methods to generate textures on surfaces directly. This approach is based on the reaction-diffusion mechanism. It will result seamless textures with no any distortion. We also propose an efficient subdivision algorithm for constructing the pigment cells on a curved surface. Then the procedural texturing process is performed on these cells directly. This avoids mapping textures from texture space to object space. We apply this approach in synthesizing textures on petals, as shown in Figure 4.

(3) The Fractal-Based Procedural Approach of Texture Synthesis

In this topic, we have an insight into the traits of iteration behaviors of complex dynamical system to characterize two fundamental patterns: the eye-like spot resulting from the basin of attraction in the Fatou set and the river-like stripe resulting from the chaotic structure in the Julia set. Underlying the theory of the Fatou set and Julia set in the dynamical system with Newton's iteration form, we propose a systematic scheme with the predictability to complex polynomial-in-Newton-form dynamical systems. Using these complex systems, we can synthesize texture patterns of the butterflies in *Satyridae*, as shown in Figure 5, and feather in *Galliformes*, as shown in Figure 6, realistically.

(4) The Synthesis of Chinese Knots

We propose a system to simulate Chinese knots. This system decomposes complex Chinese knot geometry into five basic construction units and simulates lots of existing well-known Chinese knots by organizing these construction units. Therefore, one can create new "spice" of Chinese knots in his own inspiration. Moreover, in order to offer realistic visual effects, we also propose an efficient method to simulate the fabrics details of threads. The results are presented in Figures 7 and 8.

4. Animation

Modeling the dynamics of objects to resemble them in the real world always interests scientists in computer graphics community. We describe two topics concerning the simulation of actual and realistic object's motion.

(1) The Modeling of Human Distance Running

Modeling the running behaviors of human was very attractive in animation, and many efforts have been done. In our approach, we propose a method based on mathematical formulas obtained from bio-mechanical data. It takes the advantages of intrinsic dynamics of the studied motion and extends its application context to a wider range. Since these data was obtained from actual experiments, the natural trajectory will be modeled realistically.

To reduce the excessive amount of specification for character animation, goal-directed control is necessary. We adopt the goal-directed concept to devise a **KLAR** (***Keyframe-Less Animation of Running***) system. This model consists of three levels of control mechanisms: high-level, middle-level and low-level. In the high-level control, global spatial and temporal characteristics, such as normalized length and step duration, are described. In the low-level, control a set of parameterized trajectory produces both the position of the body in space and the internal body configuration.

In the **KLAR** system, users only need to give the velocity, step length and step frequency. These parameters will be transformed into a set of step constraints for low-level control. The middle-level control mechanism is responsible for the coordination of motion and operated like a finite state machine. The middle-level mechanism manifests a stepwise reduction in the number of degree of freedom along with a decrease in the level of coordination. It consists of a stance and a swing phases in a single support state of running.

By using this method, we can smoothly synthesize the natural beauty of human distance running, as shown in Figure 9. This modeling technique can be applied to various types of human sport animation

(2) The Modeling of Cloth Animation

The modeling and animation of cloth has grown to be one of the most important fields in computer graphics. However, it is somewhat difficult to realistically animate complex cloth behaviors, such as crumpling when the cloth falling to the ground, wrinkling when a sleeve lifted by a bending arm, etc. We use a ***physically-based model*** to simulate the dynamic formation of folds, pleats, and wrinkles and the final static appearance of cloth. In our approach, cloth is first designed with polygonal panels in two dimensions, and is then positioned in three dimensions. After the cloth is created, physical properties are simulated and then cloth is animated in a physical environment. Natural effects caused by external forces such as wind and gravity can be incorporated into the model to provide the realistic cloth animation.

In order to simulate the actual behavior of the cloth on top of the physically-based model, a simulation process is proposed which can intuitively form the folds or wrinkles of cloth on the moving body. As the body moves, it causes collisions between rigid objects and the cloth (***cloth-object collisions***) and among different parts of the cloth (***self-collisions***). The simulation process includes a robust collision avoidance scheme composed of compatible cloth-object collision avoidance and self-collision avoidance.

To speedup the process of collision detection, the ***bounding boxes*** and ***hierarchical data structures*** are used to reduce the amount of intersection tests. For the cloth-object collisions, we enforce constraint over those grid points of cloth about to penetrate other objects. These constraints guarantee the cloth will end up lying on the object's surface rather than penetrating it. For the self-collisions, the bounding box technique and ordinary pre-checking techniques for collision detection is used. Instead of avoiding self-collision of cloth triangles, we relax to the avoidance of the collision of the bounding boxes of cloth triangles. Some constraints are enforced on the vertices of the cloth triangles to prevent their bounding boxes from penetration in the direction of collision. Since the types of interaction between bounding boxes are simple, it is easy in avoiding self-collisions. Finally, the simulation process combines both methods to provide penetration-free and realistic cloth animation.

The animation of cloth produced by our method is natural and realistic. The experimental results depict that our method can create realistic cloth behavior and wrinkling formation processes, as shown in Figures 10, 11, and 12.

5. Virtual Reality

Our research area for virtual reality includes switching mechanism of level-of-detail models, smooth switching in image-based virtual environment navigation, baseball hitting simulation, and virtual roller coaster.

(1) Switching Mechanism of Level-of-detail Models

In complex virtual environments, considering different levels-of-detail for displaying is an appropriate approach to achieve interactive frame rates. We have taken into account the distance between observer and object as well as view angle, effect of fog, illumination, and velocity of vehicle as the switching criteria for multiple levels of detail. The results are presented in Figure 13. In addition, a progressively switching approach for level-of-detail has also been proposed. This mechanism is applied to an application of driving simulation.

(2) Smooth Switching in Image-based Virtual Environment Navigation

The image-based virtual environment is currently a good approach in virtual reality applications. However, in current systems, walkthrough in an image-based virtual environment is generally accomplished by hopping, which could cause the discontinuity of user's view and decrease the realism of the application. We have worked out a solution to transfer smoothly between panoramic nodes by using image fade-in fade-out process rather than by hopping between them. This would greatly decrease the discomfort coming from the abrupt change of view. We have applied the proposed technology to the walkthrough of virtual NCTU campus as shown in Figure 14.

(3) Baseball Hitting Simulation

We have built up a virtual world consisting of a baseball park and a baseball. The baseball can be thrown toward home base in various styles. The user can swing a bat trying to hit the ball. The position of the bat, which is captured by 2 CCD cameras, is used to determine whether there is any collision between the baseball and the bat, as shown in Figure 15. If the bat hits the baseball, a virtual hit-ball trajectory can be shown. The proposed methodology could be applied to evaluation and adjustment of the baseball hitter's hitting gesture.

(4) Virtual Roller Coaster

We have implemented a virtual railway model, as shown in Figure 16, for roller coaster together with a force-feedback chair and a fan. When the roller coaster proceeds on the railway, the force-feedback chair declines accordingly, while the fan's rotation speed also changes in consistence with the roller coaster's speed in order to simulate the condition in a roller coaster more realistically.

6. Conclusions

In this article, we review our research works in the major fields of computer graphics and virtual reality. In the near future, we will corporate with the institute of applied arts in NCTU. We are trying to apply our technologies to the architecture design.

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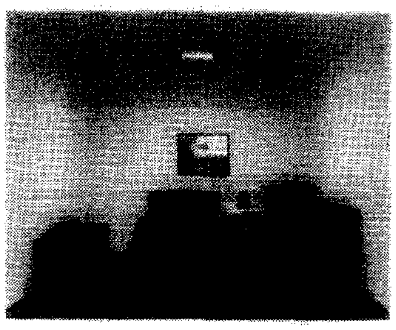


Figure 1

Figure 2

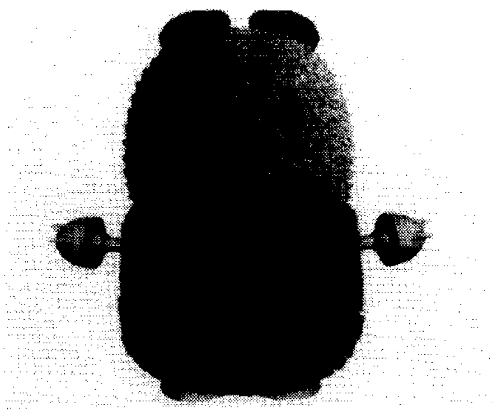
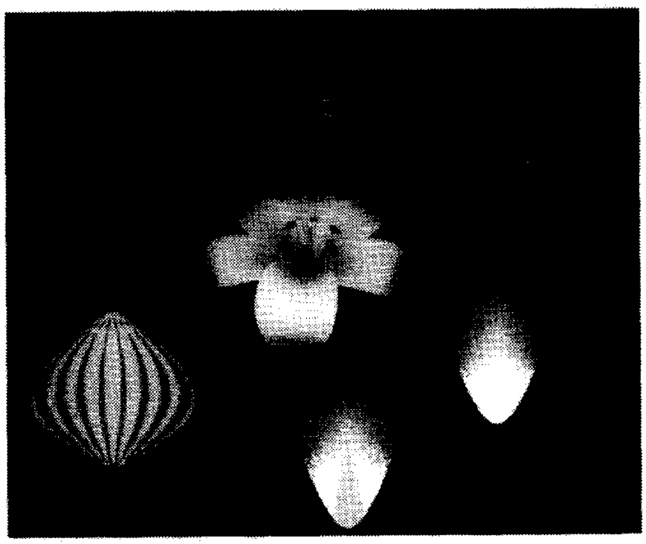


Figure 3

Figure 6



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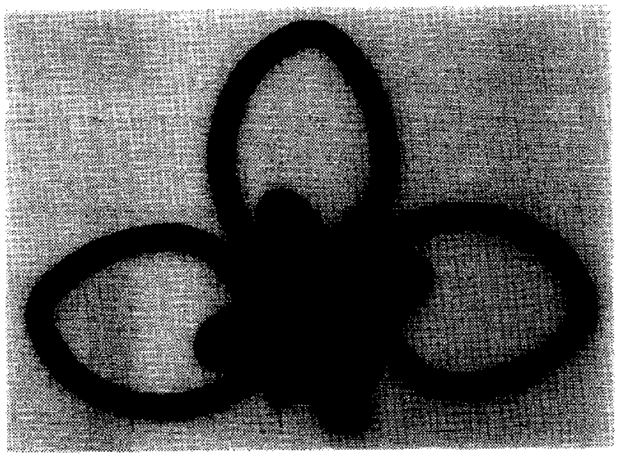

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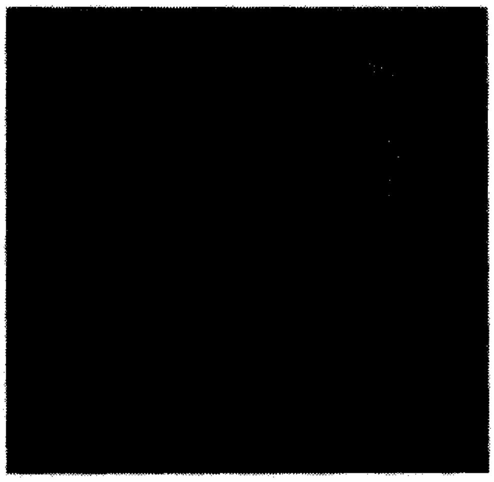

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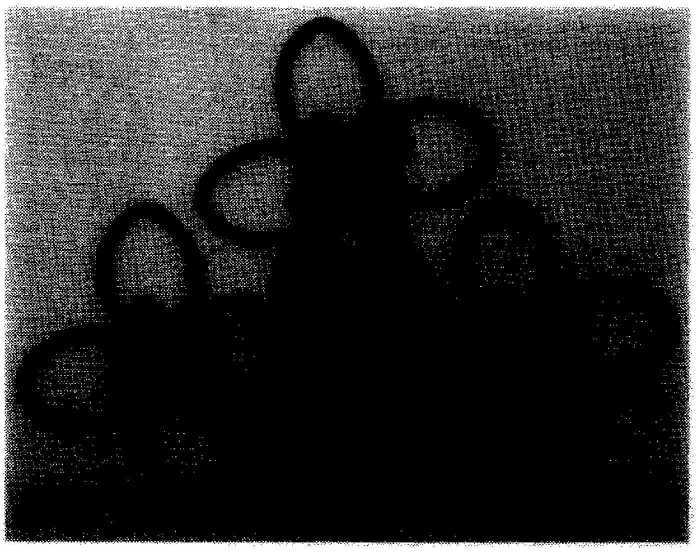

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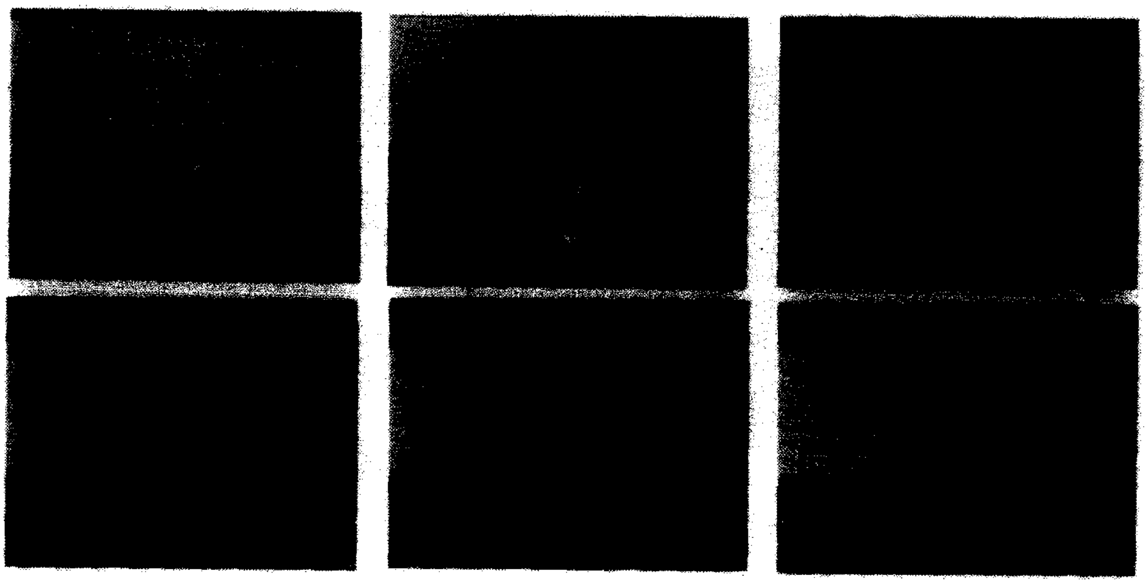

Figure 9

Figure 10

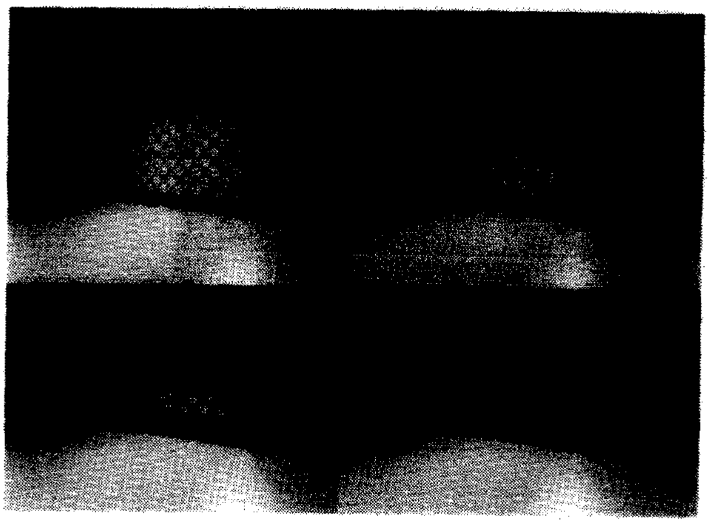

Figure 11

Figure 12

(a)

(b)

(c)

Figure 13

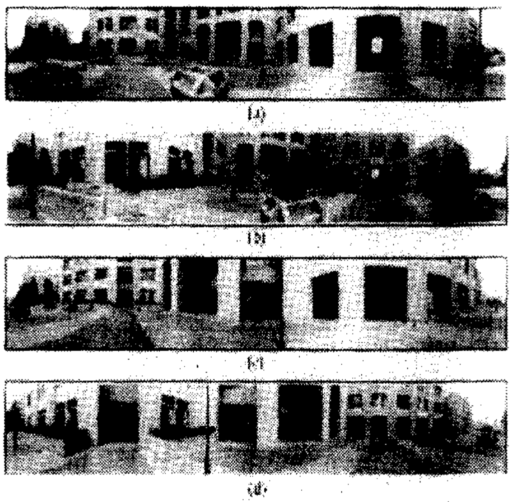

Figure 14

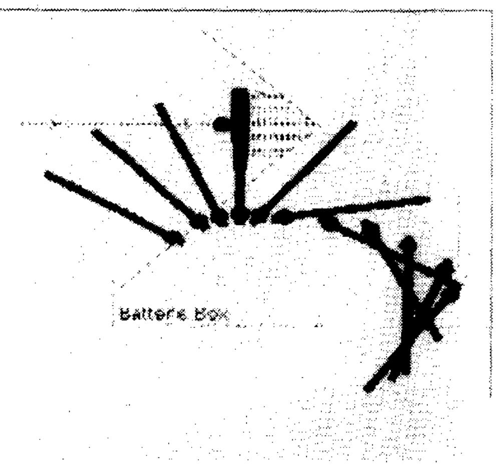

Figure 15

Figure 16