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Generation and evaluation of artificial test sequences with arbitrary 3-D objects

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Abstract

Artificially generated test sequences are of major importance in the field of image processing. A new procedure is described, which represents an economic and powerful generation process and allows a great variety of objects, motion and illumination. The internal description of the 3-D objects is based on the representation of their surface elements. This permits the generation of arbitrarily formed and textured objects.

1. Introduction

In the field of image processing the generation of artificial pictures or image scenes is of major importance. The main advantage is the enormous variation of the image contents concerning quality and quantity. In image scenes, it is possible to create 3-D objects with a great variety of form, surface and motion with a defined description.

The software package RAMON (Representation And Manipulation of three dimensiONal objects) was developed at the University of Hannover. This sophisticated software tool allows the generation of artificial test pictures or sequences with arbitrary 3-D objects. Already known and newly developed procedures were selected with respect to an economic generation process (concerning computation time, etc.) and with a great variety of the kind of objects, motion and illumination.

One application of artifically generated test sequences is the evaluation of motion estimation procedures. The analysis of errors can be carried out on the basis of these test sequences and be compared for all known algorithms.

2. Features of the software tool RAMON

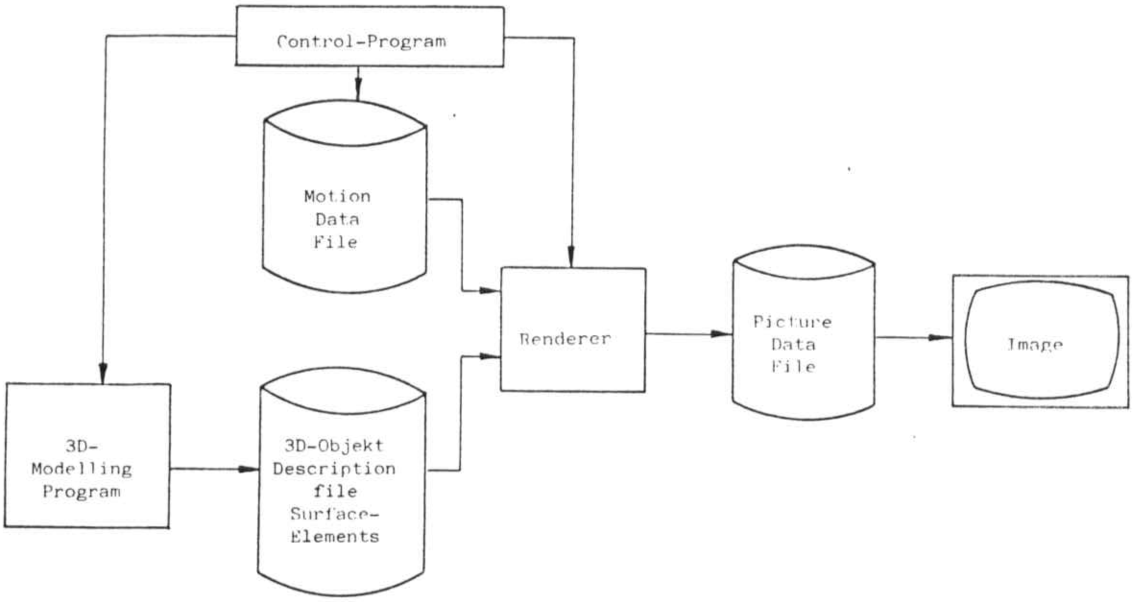

Figure 1. Block diagram of the software tool RAMON

RAMON enables the perspective projection of arbitrary non-transparent three-dimensional objects with surfaces from matted to specular and arbitrary surface textures. The camera parameters, such as position, orientation of the optical axis and focus can be freely chosen. The illumination is possible either as matted or as an oriented light source, whereby intensity and orientation can also be freely selected.

To save computation time, the representation of multireflection between specular objects, the generation of transparent objects and shadowing are not realized.

Figure 1 shows the basic concept of RAMON. The internal description of the 3-D objects is optimized with respect to an efficient computation for the generation of an image sequence, without any restriction concerning the form of the objects. The generation of the objects is therefore independent of the computation of the images. On the basis of the object description and the projection equation it is possible to directly create an image, after having fullfilled a coordination transform which considers the camera and object position.

The software package is written in FORTRAN 77 and runs on the computer family VAX 11/7xx under VMS.

3. Internal description of the objects

The three-dimensional objects are represented by their surfaces. The surface is decomposed in surface elements. Each surface element is defined by its position vector (X, Y, and Z components), the orientation of the surface with the unit vector, the colour of the element and the kind of reflection (from specular to matted). The compactness of the surface elements is variable.

This special description allows the representation of arbitrarily formed and textured objects. The advantage of this procedure is the relatively simple kind of object description whereas the disadvantage has to be seen in the relatively large amount of storage capacity. This disadvantage is not of great importance since a large amount of mass storage capacity is normaly available in an image processing environment.

The surface elements of an object are stored in a file on the mass storage. For sequences with rigid bodies, it is necessary to calculate the surface elements only once. The computation time for the generation of an image is therefore only dependent on the size of the surface of the objects.

3.1 Generation of objects

The surface elements are samples of the object surface. This representation of three-dimensional objects permits the separation of an internal description of the objects and the generation of an artificial image. For the calculation of the projection of the 3-D object, the kind of object description is irrelevant.

The surface elements can be generated on the basis of a volumetric model representing primitive objects, on a parametric description of the surface, e.g. splines, quadric surfaces, or on an image analysis procedure, whereby a couple of selected views have to be taken.

3.2 Primitive objects

Simply formed objects can be composed of a set of primitive objects. The following primitive objects have already been realized: spheres, cones, toruses, quaders, cylinders. On the surface of these objects, it is possible to project a picture. These primitive objects may be arbitrarily composed and penetrate each other.

3.3 Parametric description of the surface

The surface of more complex objects can be described with polygons or free-form areas which are created, for example, with spline functions.

3.4 Modelling of natural objects

The description based on surface elements also allows the representation of very complex-formed natural objects. For this application, an image analysis procedure is necessary, which permits an automatic modelling of the surfaces on the basis of selected views of natural objects. In this context, a decomposition of the surface of the natural object in polygons or other parametric sub-surfaces is not required.

At the University of Hannover, new procedures are being developed, which make a modelling of three dimensional objects of an image scene possible. With the aid of these techniques, a highly sophisticated tool is available which reduces the modelling process essentially.

4. Image generation

The computation procedures of two-dimensional images of three-dimensional objects can be roughly classified into two groups.

I. Procedures starting from the image plane going along of a ray and scanning the space until an object is found, the so-called "ray-tracing procedures".

These procedures allow images to be generated which give a very realistic impression of artificial images with specular and transparent objects, with shadow and multireflection. However, the computation time is very high. For example, the computation time for one image with a couple of specular objects /1/ ("image of a mirrored room") is approximately 4 to 8 hours for a VAX 11/780.

II. Procedures which start from one point of the surface of the object and then determine the position of its projection in the image plane.

One procedure of this group is the "z-buffer algorithm", which is used in RAMON. On the basis of this algorithm the computation time of the generation of images with 3-D objects is substantially reduced and, additionally the degree of freedom is higher. The description of multireflection is not possible with this procedure.

4.1 Projection

For the generation of an image, the surface elements, which describe the surface of the objects, are serially read from a mass storage. The order of processing of the single surface elements can be arbitrary. The projection of the surface point results in the corresponding position in the image plane. Parallel to the image plane, the distance of the shown surface element from the image plane is stored in the z-buffer. Only those surface points are stored whose distance is smaller than that of surface points aready stored. Covered object parts are not representable with this technique.

4.2 Shading

The calculation of the resulting brightness of a surface element in the image is based on the proposal of Phong /2/. The brightness results from the intensity of a directed light source and from the matted and specular part of the reflection of the object as well as from a part of the matted background illumination.

4.3 Anti-aliasing

A basic problem in the generation of artificial images is the appearance of a step-like structure in the image, especially well visible at diagonal object edges. The reason is that the sampling theorem is ignored. A reduction of the alias effect is possible by subdivision of a pixel into subpixels. The final image can be reached by a low-pass filtering and a following reduction of the subpixel image. The advantage of this procedure is that it can be realized independently of the 3-D modelling.

The computation cost depends on the number of subpixels. A reasonable compromise between image quality and computation time has to be made. In most cases a subdivision into four subpixels hardly leads to visible alias effects.

5. Animation

For the generation of single images, the camera, the light sources and the objects can be positioned arbitrarily. Therefore, any kind of motion in image sequences can be shown. The motion parameters have to be extra determined in special cases. RAMON uses a simplified animation concept which is acceptable for a great variety of image sequences.

Single objects can be combined to compositions, the position of an object in this composition being arbitrary. The compositions are independent of one other so that the same object can always be used in different combinations. The motion parameters, translation and rotation are defined for each composition. For the generation of an sequence, the starting and end points of the position of objects or compositions, the camera and the illumination and the number of images have to be determined. Between the the first and the last image, a continuous motion is assumed.

6. Examples of images

6.1 Single images

Figure 2 shows a composition of different primitive objects. For the generation of an image, this composition can be used as that of a single object. Figure 3 shows an example for the multiple application of a composition in different positions. Figure 4 describes an example of the penetration of objects in a composition. On the surface of the sphere the projection of the composition is shown.
As an example for a free-form area, a flag with different shaping is shown in Figure 5.

6.2 Image sequences

Figures 6 shows the first and the last image of an image sequence with 96 frames. The sequence consists of four motion objects. The position of the camera and the focus are also changed. The sequence is coloured. The computation time for this sequence is approximately 8 hours on a VAX 11/780.

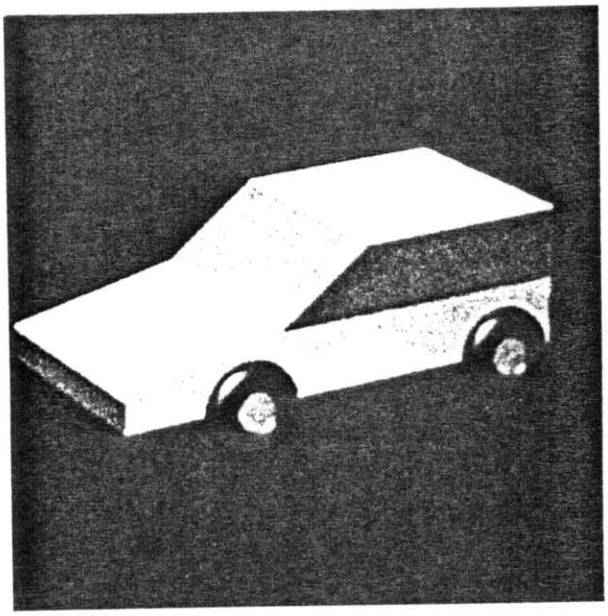

Figure 2. Composition of different primitive objects.

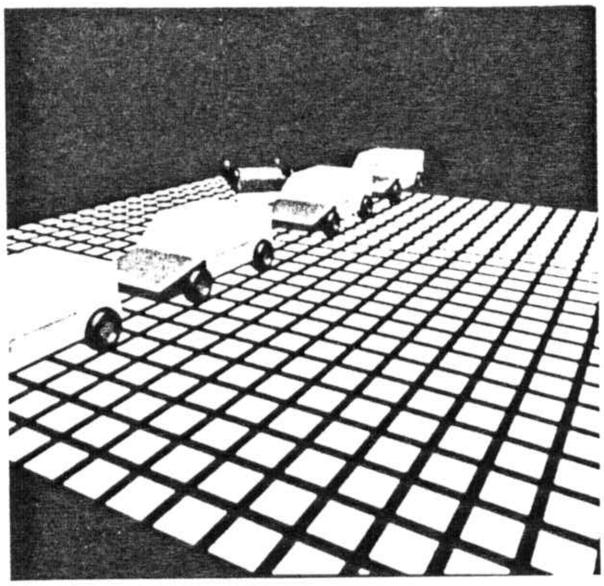

Figure 3. Multiple application of a composition in different position.

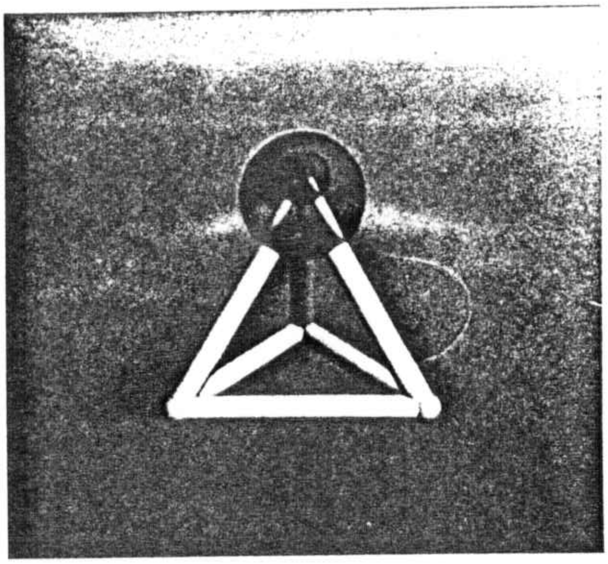

Figure 4. Example of the penetration of objects in a composition.

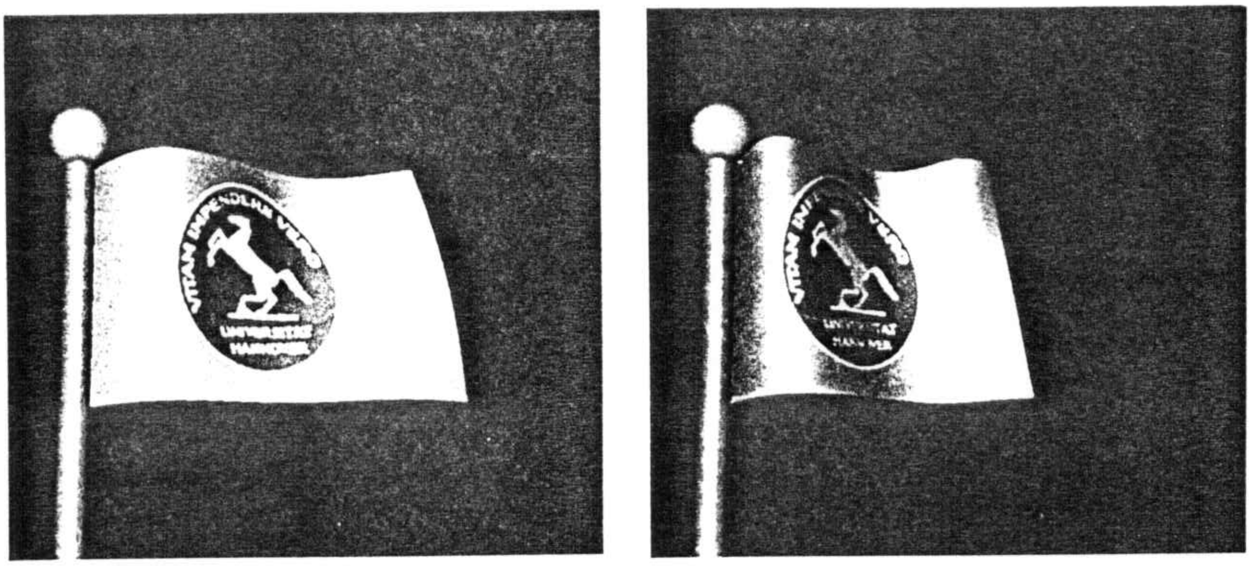

Figure 5. Example for a free-form area, a flag with different shaping.

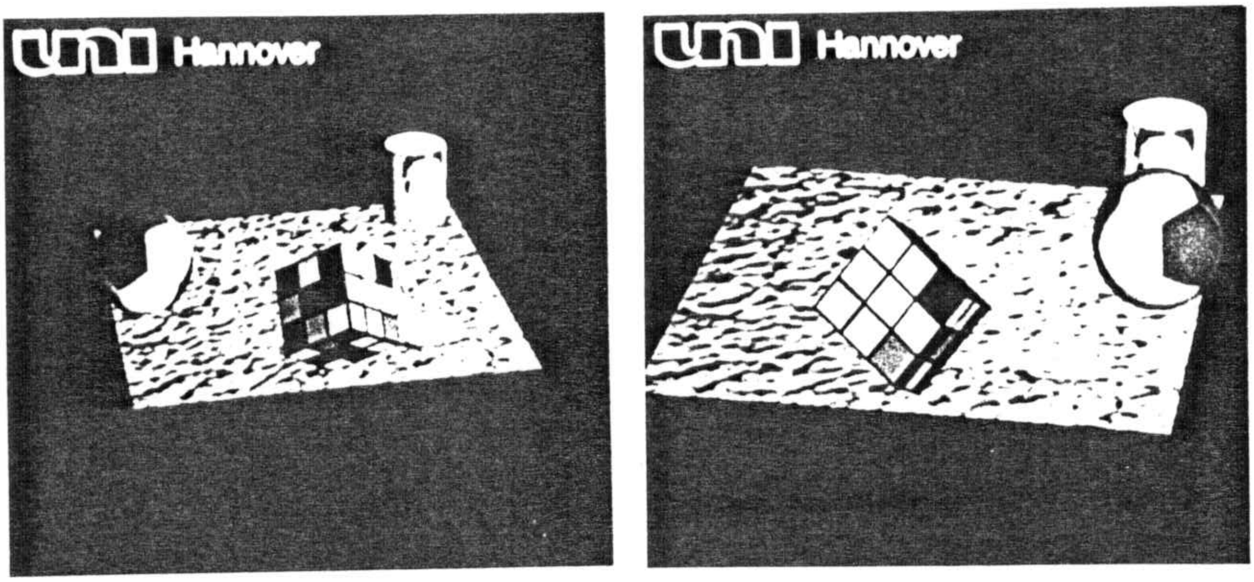

Figure 6. First and last image of an image sequence with 96 frames (coloured).

7. Motion estimation

7.1 General approaches

Image sequence processing involves a large amount of data. One of the most important issues in image sequence processing is motion estimation. In many image processing problems, motion estimation is the key issue. For example, in efficient coding using DPCM in time, motion estimation and compensation can essentially improve the efficiency significantly. Applications are dynamic robot vision, data reduction of TV signals, study of motion for medical problems, tracking problems, etc.

The analysis of image motion is still in its infancy. Most of the past work /3/ was restricted to two-dimensional motion, especially translation. There have been three major approaches to estimating two-dimensional translation: Fourier method, matching procedure and the method of differentials. All three approaches can be extended to apply to the estimation of general two-dimensional motion. However, the well-known techniques ignore many important factors, such as radiometric considerations, occlusion and deformable bodies. To solve this problem further studies on motion estimation are necessary.

7.2 Evaluation of motion estimation procedures

As already mentioned, motion analysis is still in its infancy. However, it is necessary to evaluate the different approaches considering a specific application. The common problem is the determination of the accuracy of the motion parameter estimation depending, on the one hand, on the kind of motion (translational, rotational, zooming) and, on the other hand, on the type of objects (form shape, running occlusion, etc.). Also of importance is the stability i.e. how often the algorithm cannot give any acceptable result. An interesting proposal for the solution of the evaluation problem is the generation of an artificial test sequence with different 3-D objects. The main advantage is the already known motion and the type of each object. For various applications, it is necessary to generate a couple of test sequences with different complexity.

Preliminary results have shown that a number of fundamental problems of motion estimation have not yet been solved:

- Displacement does not exist by scene cuts or decovered background
- Displacement is not sufficient to describe signal changes, such as spatial resolution changes, illumination changes or noise.
- Displacement is not uniform for signals which are constant along some spatial direction or with periodic structures.
- Displacement is rapidly varying spatially on objects borders and in the case of rotation.
- Displacement estimate is not accurate for large displacements.

Further study is necessary to evaluate different motion estimation procedures.

8.Conclusion

The key point of this contribution has been the description of a highly sophisticated software package for the generation of single images or sequences with arbitrary 3-D objects. The representation of arbitrarily formed and textured objects is possible. The camera parameters and different illuminations can be chosen freely. Any kind of motion in image sequences has been shown. The internal description of the 3-D objects is optimized with respect to an efficient computation for the generation of an image sequence.

One application has been described which makes use of the artifficially generated test sequences for the evaluation of motion estimation procedures.

References

/1/ Hall, R. A.; Greenberg, D. P. A Testbed for Realistic Image Synthesis, IEEE CG&A Nov. 1983.

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/3/ Huang, T.S. et all Image Sequences Analysis, Springer Verlag, New York, 1981.