Pencil Tracing Mirage: Principle and its Evaluation

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Figure 1. *Images of square sun mirage generated by our method.*

1. Introduction

To generate realistic representation of the nature scene is one of the most challenging areas in the computer graphics community. Ray tracing[1] is the most well-known technique to synthesize a realistic image. Since ray tracing is the most suitable method for simulating reflection and refraction of the light, it has been used for simulating atmospheric optical phenomena due to reflection and refraction of the light. The mirage is a kind of atmospheric optical phenomenon. Therefore, it is possible to synthesize mirages in 3DCG by simulating or modeling condition of the air. We focus on pencil tracing technique[2] that is an extention of conventional ray tracing technique based on the paraxial approximation theory. Our simple method based on pencil tracing can efficiently generate an appearance of mirage without any complex thermodynamic simulation.

2. Proposed Method

We extend the pencil tracing method to synthesize mirages. Our idea is to introduce a special kind of object in scene, and integrate a perturbation factor into image generation process of the pencil tracing. Our method is useful because it can treat perturbation of the air as simply matrix product.

2.1 Pencil Tracing

The pencil tracing is a method for accelerating image generation of the ray tracing method by tracing a pencil (or bundle) of rays instead of an individual ray. Thus, a ray is not traced per a pixel or a sub-pixel, it is traced per domain of pixels. *An axial ray* (center ray of domain) is traced in the same manner as ray tracing, but *paraxial rays* (surrounding rays of the axial ray) are omitted to be traced by using result of tracing their axial ray. Therefore, pencil tracing is faster than the conventional ray tracing. In this method, an optical system affecting a path of the axial ray is represented as 4x4 matrix called *system matrix*, and a ray is represented as 4D vector called *ray-vector*. Paraxial rays changed by the optical system are approximated by the transformation of their ray-vector representation with the system matrix. This is formulated as follows:

$$\boldsymbol{\psi}' = T\boldsymbol{\psi}$$

Here, $\boldsymbol{\psi}, \boldsymbol{\psi}'$ are ray-vectors of an original ray and of a transformed ray, respectively. T is a system matrix.

2.2 Perturbation Object and Matrix

Most of mirages have fluctuated appearance due to perturbation of the air. It is one of the most important factors of the mirage appearance. To synthesize this, we introduce *a perturbation object*. This is a special kind of scene object that adds positional and directional noise to a ray. To integrate this operation of addition into the form of matrix product, we extend a system matrix to 5x5. Extended system matrix and one for the perturbation T_P is as follows:

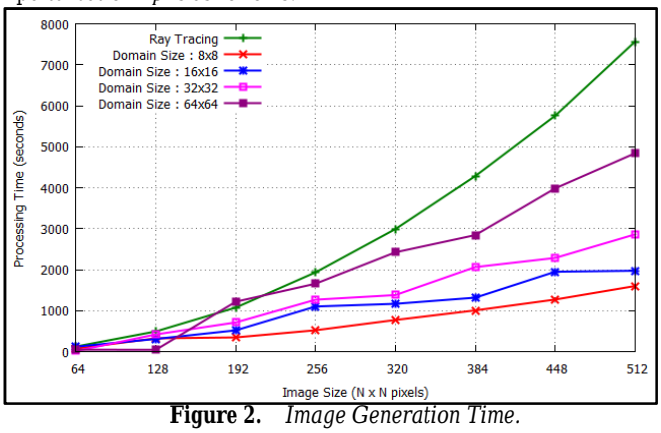

Figure 2. *Image Generation Time.*

$$T' = \begin{pmatrix} T & \mathbf{0} \\ \mathbf{0}^t & 1 \end{pmatrix}, T_P = \begin{pmatrix} e & \boldsymbol{\psi}_\varepsilon \\ \mathbf{0}^t & 1 \end{pmatrix}$$

Here T is a 4x4 system matrix and $T'$is its equivalent extended matrix, e is a 4x4 identity matrix, $\boldsymbol{\psi}_\varepsilon$ is noise ray-vector, and $\mathbf{0}$ is 4D column zero vector.

3. Results

As shown in Fig.1, images of square sun mirage are generated by our method. These images are a part of the short video (450 frames). Compared to the actual video (see the supplemental video), realistic images are successfully generated.

All the images of Fig.1 are generated by the following computer environments: CPU - Intel Core i7-920 (2.66GHz), system memory - 16GB. We measured the image generation time of a variety of sizes of images and sizes of domains. Figure 2 shows the generation time of 450 images of square sun mirage. Measurement results verified that our method can generate images about 1.5-5 times as fast as the conventional method.

4. Conclusions

We proposed a pencil tracing technique for synthesizing mirages. Our method generated images of square sun mirage fast and efficiently.

References

[1] WHITTED, T, 1980. An Improved Illumination Model for Shaded Display. Comm. ACM. 23, 6, June 1980, 343-349.

[2] SHINYA, M., TAKAHASHI, T., NAITO, S, 1987. Principles and Applications of Pencil Tracing. *SIGGRAPH Comput. Graph.* 21, 4 (August 1987), 45-54. DOI=10.1145/37402.37408