Image Shading Taking into Account Relativistic Effects

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This article is concerned with creating more realistic images of 3D scenes which are moving relative to the viewer at such high speeds that the propagation delay of light signals and other relativistic effects can not be neglected. Creating images of 3D scenes in relativistic motion might have important applications to science-fiction films, computer games, and virtual environments. We shall discuss the following problems: (1) how to determine the visual appearance of a rapidly moving object, (2) how to determine the apparent radiance of a scene point on a moving object, (3) how to determine the incident irradiance at a scene point coming from a moving light source, (4) how to determine the color of a rapidly moving object, and (5) how to generate shadows when there are relative motions between the viewer, the scenes, and the light sources. Detailed examples are also given to show the result of shading with the relativistic effects taken into account.

1. INTRODUCTION

In traditional computer graphics, an underlying assumption is that the speed of light is infinite or the speeds of the scenes relative to the viewer are very small compared to that of light so that the propagation delay of light signals and other relativistic effects can be neglected. For example, in some science-fiction movies and computer games, an object (e.g., a space ship) may move with a speed comparable to that of light, but nothing in its shape, brightness, color, or shadow shows the consequences of special relativity. Although we can not experience directly the fundamental phenomena that special relativity predicts, one would like to experience the
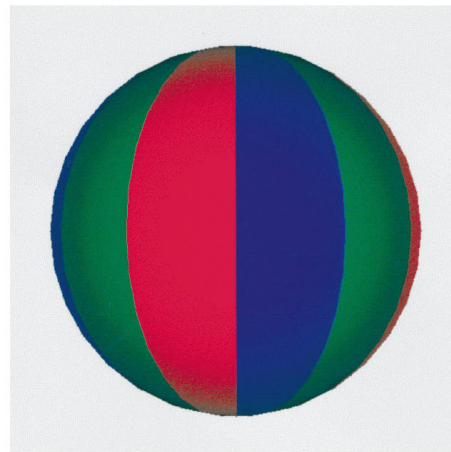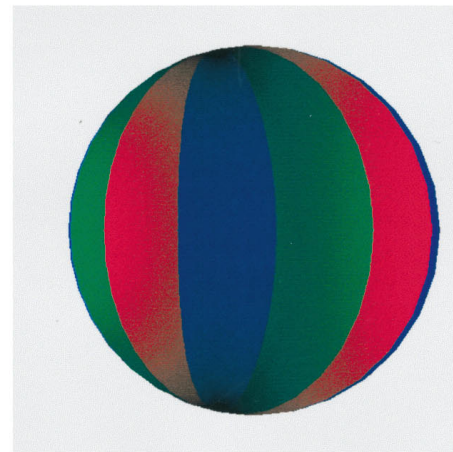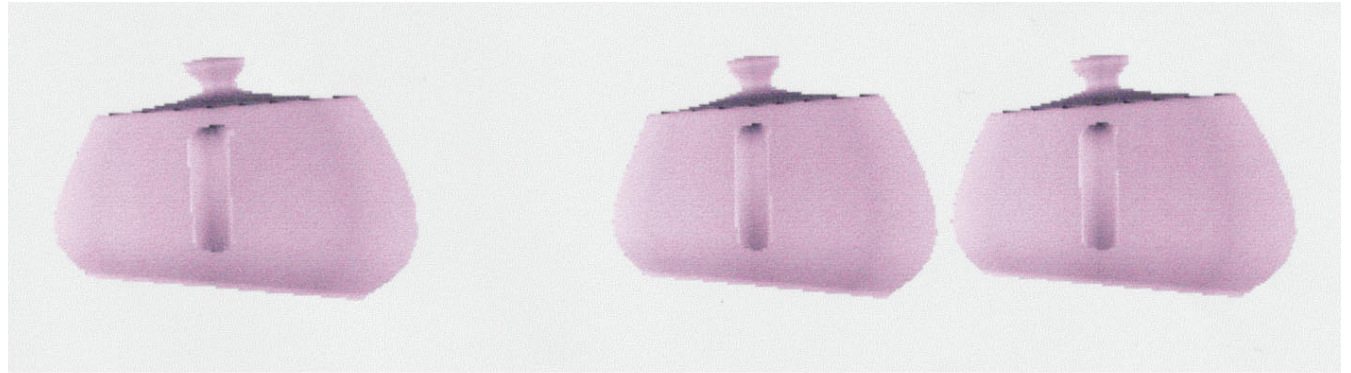
(a)

(b)

(c)

(d)

(e)

(f)

Fig. 9. The visual appearances of objects moving at relativistic speeds. All the objects in the examples are moving relative to the viewer O with velocity $\mathbf{v} = (0.95c, 0, 0)$. The left images (a), (c), (e) show the original shapes of the objects. The right images (b), (d), (f) show the visual appearances of the objects for the viewer O.
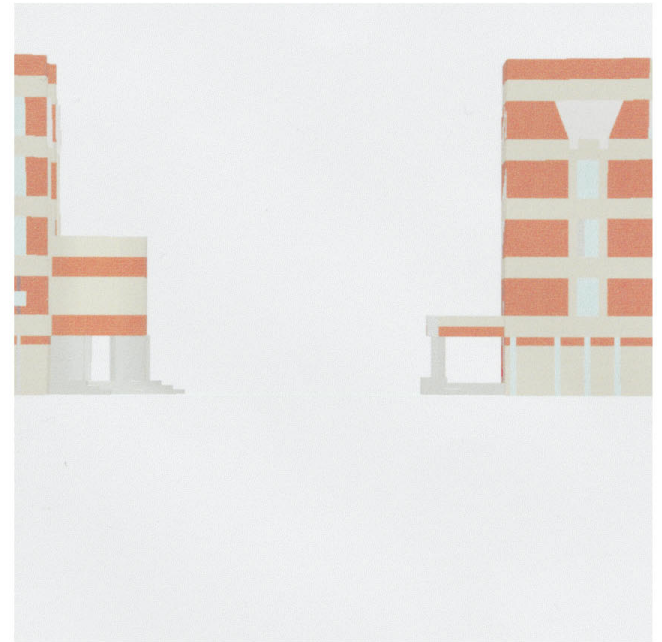
Fig. 10. Visual appearance of a moving teapot. (a) The teapot is still relative to the viewer. (b) The teapot is moving from the left to the right with a speed of $0.95c$. (c) The teapot is moving from the left to the right with a speed of $0.999c$.

Fig. 11. Original appearance of the STREET.

Fig. 12. Apparent appearance of the STREET with respect to a moving viewer. (a) The viewer is rushing into the street with a speed of $0.99c$. (b) The viewer is rushing out of the street with a speed of $0.99c$.

(a)

(b)

Fig. 15. Effects produced by the motion of light sources. (a) The teapot is moving relative to the viewer with a velocity of $(0.95c, 0, 0)$, and the light sources are at rest in the coordinate system of the viewer. (b) The light sources are moving relative to the teapot with a velocity of $(-0.95c, 0, 0)$, and the viewer is still relative to the teapot.

Fig. 17. Variation in color due to the Doppler effect. The teapot is moving from the left to the right with a speed of $0.5c$, and the light sources are at rest in the coordinate system of the teapot.
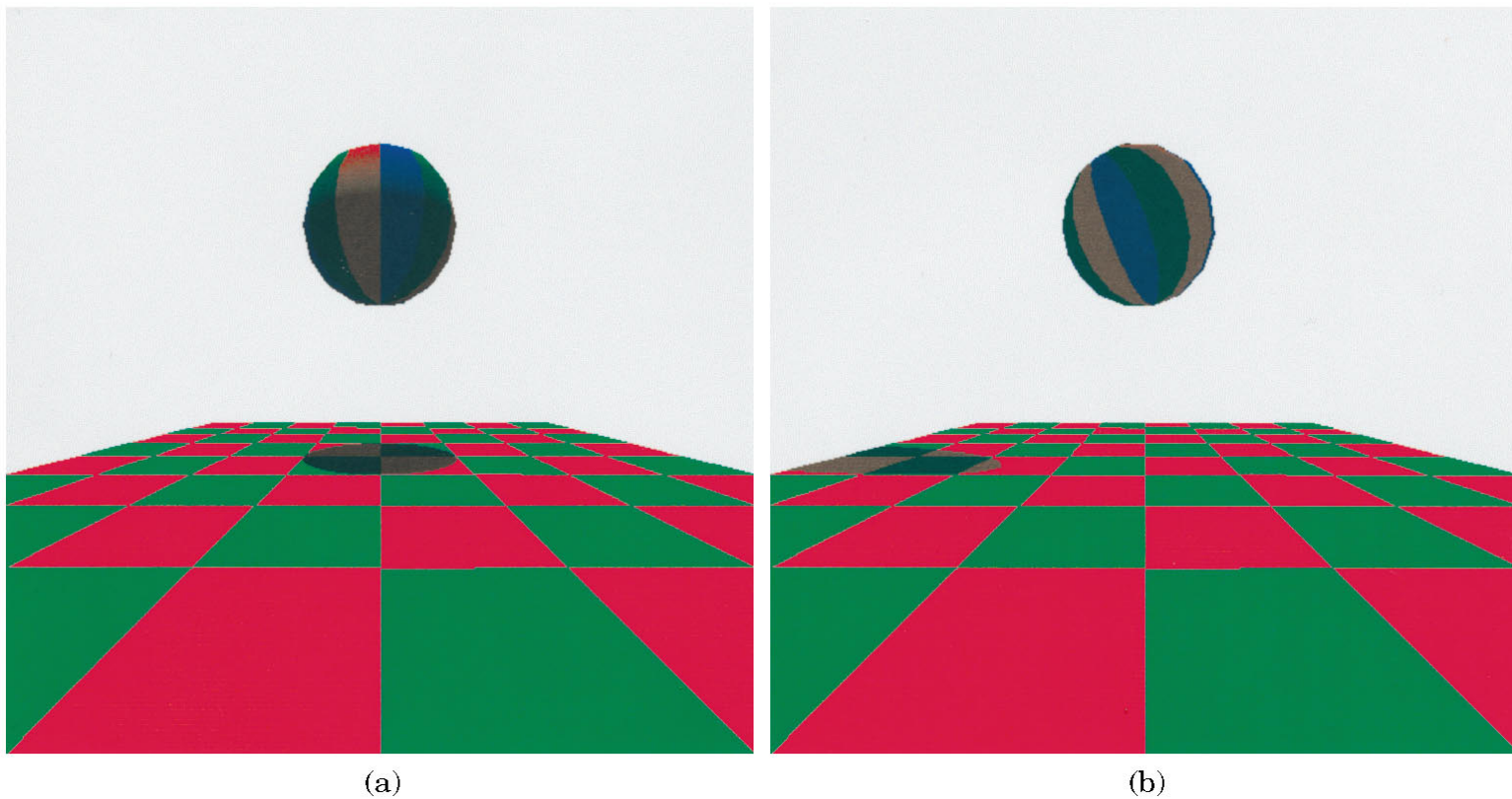
Fig. 18. Effect of generating shadows with the relativistic effects taken into account. (a) The sphere is still relative to the viewer. (b) The sphere is moving with a velocity of $(0.95c, 0, 0)$ with respect to the viewer.