OpenGL Specular Reflections Caused by Light Source Placed Below Shadowed Object

Dženan F. Avdić, Dejan D. Rančić, Aldina R. Avdić and Petar Ć. Spalević

***Abstract*— Reflections and shadows are crucial for enhancing scene realism and providing important visual cues. In recent years, many important contributions have been made in modeling both for shadows and for reflections which are consequences of the presence of objects made of special material, with the mirror effect. Shadows are created by a light source that is placed above the shadowed object. Those shadows are placed on the surface where the shadowed object is placed. But, if a point light source is placed below a shadowed object made of a material that reflects light, the phenomenon that is created on that surface is not a shadow. This specular reflection is a topic that will be described in this paper, on the example of circle and sphere object.**

***Index Terms*— Circle, OpenGL, Point light source, Reflections, Shadows, Sphere.**

I. Introduction

Making a virtual reality using computer graphics is a fundamental part of implementing computer games, CAD software, software dedicated to various types of simulations, etc. The existence of phenomena that are caused by the presence of light sources in the scene, such as shadows and reflections, is essential for the improvement of visual perception. Since their using depicts relations between objects on the scene, users can sense more exactly the distance between two virtual objects. So, those components enhance the 3D impression to users can get a better immersive 3D feeling [1, 2].

Shadow is an area where direct light from a light source cannot reach due to obstruction by an object. It occupies all of the space behind an opaque object with light in front of it. The cross-section of a shadow is a two-dimensional silhouette or reverse projection of the object blocking the light.

For a non-point source of light, the shadow is divided into the umbra and penumbra. The umbra is a dark component of shadow, and its creation is a consequence of the fact that there is the area of a shadowed object that is not visible from any part of the light source. Light sources with their area can make another component of shadows which is less dark from the umbra. It happens when the area of a shadowed object that can receive some but not all, of the light from the light source [3].

So, a point source light has no penumbra, since no part of a shadowed object can receive only part of the light [4].

Reflection is the change in direction of a light ray at an interface between two different media so that the light ray returns into the medium from which it originated [5]. The law of reflection says that for reflection the angle at which the ray is incident on the surface equals the angle at which it is reflected.

If the reflecting surface is very smooth, the reflection of light that occurs is called specular or regular reflection. Otherwise, if the reflecting surface is rough, reflection is diffuse. The laws of reflection are as follows (shown in Fig. 1):

- The incident ray, the reflected ray, and the normal to the reflection surface at the point of the incidence lie in the same plane.
- The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal.
- The reflected ray and the incident ray are on the opposite sides of the normal.

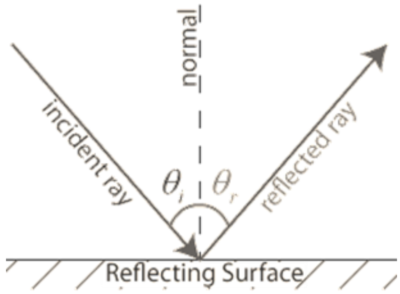

Fig. 1. Rays and angles in reflection

Refraction is the change in direction of a wave due to a change in its medium. It is essentially a surface phenomenon. Due to the change of medium, the phase velocity of the wave is changed but its frequency remains constant. This is most observed when a wave passes from one medium to another at any angle other than 90° or 0°. Refraction of light is the most observed phenomenon, but any type of wave can refract when

Dženan F. Avdić is with State University of Novi Pazar, Department of Technical Sciences, Vuka Karadžića bb, 36300 Novi Pazar, Serbia, (E-mail: dzavdic@np.ac.rs)

Dejan D. Rančić is with University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, (E-mail: dejan.rancic@elfak.ni.ac.rs)

Aldina R. Avdić is with State University of Novi Pazar, Department of Technical Sciences, Vuka Karadžića bb, 36300 Novi Pazar, Serbia, (E-mail: apljaskovic@np.ac.rs)

Petar Ć. Spalević is with University of Pristina, Technical Sciences, Knjaza Milosa 7, Kosovska Mitrovica, Serbia, (E-mail: petar.spalevic@ftn.pr.ac.rs)

it interacts with a medium, for example when sound waves pass from one medium into another or when water waves move into the water of a different depth.

Refraction is described by Snell's law, which states that for a given pair of media and a wave with a single frequency, the ratio of the sinus of the angle of incidence θ1 and angle of refraction θr is equivalent to the ratio of phase velocities (v1 / v2) in the two media, or equivalently, to the opposite ratio of the indices of refraction (n2 / n1) is given with eq.1:

$$\frac{\sin\theta_1}{\sin\theta_r} = \frac{v_1}{v_2} = \frac{n_2}{n_1} \quad (1)$$

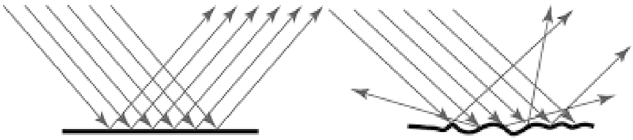

Fig. 2. Specular and diffuse reflection

Reflection in computer graphics is used to emulate reflective objects like mirrors and shiny surfaces.

OpenGL does not support reflections directly, but some kinds of these can be implemented in several ways. The methods vary in their difficulty to implement, their performance, and the quality of their results. These qualities depend on two parameters: the complexity of the observed object and the complexity of the scene where this object is placed [6, 7, 8].

The approach described in this paper supports makes the formation of specular reflection easier, considering the events that occur when objects are exposed to the light. In this example, the light source is a point source of light, and the surface, on which the light rays to form a shadow, is flat.

The aim is to determine the minimum number of characteristic rays coming from the light source and points out that these rays pass, which are essential for the formation of specular reflection on the surface [9]. Reflections are created for two types of objects (circle and sphere).

The paper is organized as follows. The first section provides an overview of the existing methods, with emphasis on their advantages and disadvantages. The next section presents the mathematical base for the formula derivation, which allowed finding characteristic points for drawing reflections. Then follows the description and view the experiment in which an application is created based on the formula, and the results are displayed. Finally, conclusions and trends in future work are given.

II. RELATED WORK

Reflection is accomplished in a ray trace renderer by following a ray from the eye to the mirror and then calculating where it bounces from, and continuing the process until no surface is found, or a non-reflective surface is found. Reflection on a shiny surface like wood or tile can add to the photorealistic effects of a 3D rendering.

Polished - A polished reflection is an undisturbed reflection, like a mirror or chrome.

Blurry - A blurry reflection means that tiny random bumps on the surface of the material cause the reflection to be blurry [10, 11].

Metallic - A reflection is metallic if the highlights and reflections retain the color of the reflective object.

Glossy - This term can be misused. Sometimes it is a setting which is the opposite of Blurry. When "Glossiness" has a low value, the reflection is blurry [12, 13].

Reflections have applications in the study technique. This is described in [14] but in the case of the ray-tracing technique.

III. IMPLEMENTATION OF SPECULAR REFLECTIONS

The goal of this research is to establish a single library with methods for adding specular reflections after drawing an object, in case that the light source is below that object. As the reflections will be realistically drawn for each of the primitives, complex objects consisting of 2D and 3D primitives will have their own reflection which will be formed by the reflection of its component objects. This approach uses the phenomena that occur in the real-world in the case when the scene is lighted by a point source of light, which can move along the axis of the coordinate system.

The effectiveness of these ways of the rendering of reflections is in the fact that there is a need to calculate minimum points relevant for drawing them. The second circumstance is the use of the fact that there are similarities between reflections of the primitives. A sphere is made by the rotation of a circle around one of the axes. So, with finding a method for forming the reflection for 2D objects, it is easy to create the reflection for the 3D object.

The paper describes the following case. For two objects (circle and sphere) that are located away from the surface for a distance d, the reflection is on the surface that is created by the point light source with the possibility of movement. The surface is flat. The light source can move the X and Y axes.

Due to many options and restrictions for showing 3D system on 2D paper, some less relevant parameters for calculating the are taken as fixed:

- The light source is always below the object (yi < yp + hp)
- X and Z coordinates of the object are point 0.
- xi, yi, zi are the coordinate position of the light source (zi = 0)
- r is the radius of the circle and the sphere.
- d is the distance between the object and the surface.
- xp, yp, zp are coordinates of the center point of the object (for circle it is the circle's center, also for the sphere) (xp, zp = 0).

A. A Circle

In this case, the object which is considered is a circle. The events that occur when the light source is below the circle which is set parallel to the flat surface are monitored. This means that the value of y coordinate object (circle) is higher than the value of y coordinate sources of light. A phenomenon which is then displayed on the surface is not a shadow of the object, but rather a reflection object (circle). It examines the case of the circle, as it is in the structure for other elements, so the reflection of more complex objects which have a circle in its basis calculates using the reflection of the circle.

According to the theoretical basis of which is given in the introductory part, the light is reflected from all points of a case on the same angle at which it came to that point. As stated in working with composite shadows [10], there is no need to look at all points and looking for reflections of each item that belongs to the circle. This would make rendering significantly complex. What we concluded lightening circular object of negligible thickness mounted parallel to the surface, if the light source is below the observed object, is that the shape of its reflection is also a circle.

Two cases are considered: when the light source is just below the circle (x = xp = 0) (Fig.3.a) and when the light source is placed to the left or right of the object (Fig.3.b).

An important point is the center of the reflection. Also, important information needed for rendering is the size of the radius of the reflection. Coordinates of the center of reflection could be found as follows. First, we need to find a point that is the symmetric center of the light source relative to the center of the circle, i.e. in this case to the y-axis. In this way, the ray is reflected light is passing right through the center of the circle and the symmetric point. The intersection of the reflected rays of light and surface reflectance is the center of the circle on the surface.

If the source of light just below the object, the coordinates of the center of reflection are known and they are coordinates of the beginning point (0, 0, 0). If not, the formula for calculating the center of the reflection is given with (2).

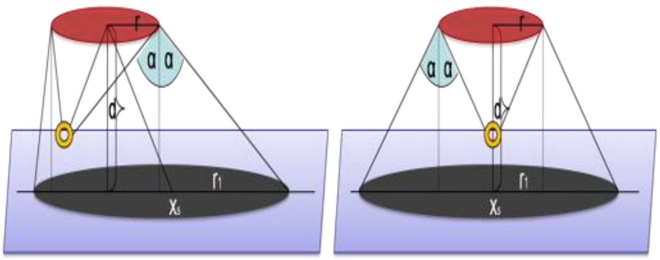

Fig. 3. A reflection of the circle on the plat surface using a point light source: left) Xi=Xp=0 right) Xi≠Xp

$$x_s = \frac{d \cdot x_i}{y_i - d} \tag{2}$$

To calculate the length of the radius of reflection, we should have to watch the ray of the light that is reflected from two points on the circle, i.e. to watch endpoints diameter circle when the x coordinate of a diameter equal to zero. The process of finding reflected rays is carried out in the same manner as in the case of finding reflected rays from the center point of the circle.

The equation for calculating the radius of the reflection is given in (3). From this formula, the length of the radius depends on r, yi, and d.

$$r_1 = \frac{-d \cdot r}{y_i - d} + r \tag{3}$$

The reflection of the circle is a circle with its center at the center is (xs, 0, 0), and which radius is r1.

Including the equation h=yi-d, equations 2 and 3 can be expressed as eq.4 and eq.5:

$$x_s = \frac{d \cdot x_i}{h} \tag{4}$$

$$r_1 = \frac{d r}{h} + r \tag{5}$$

B. A Sphere

A sphere is a 3D object that is created by circle rotation around the X-axis but shifted to r on Y ax.

When we look at creating a sphere reflection caused by placing light sources under the ball, what can be concluded is that a large part of the sphere is not visible from the light source. Light affects only one part of the sphere. The reflection of the sphere is equal to the reflection of this part, i.e., its largest circle. The problem of creating reflection is reduced to finding the intersecting circles, from whose center and endpoints light rays bounce from the center of the point source of light. The condition that must be fulfilled to have a reflection of the sphere which has its shape, i.e. not to waste all over the place, is that the absolute value of x coordinates of the light source is less than the radius of the sphere, in case of the sphere whose center is at (0, y), as shown in Equation 6.

$$|x_i| < r \tag{6}$$

In this case, it is necessary to find a tangent to the circle sphere whose center is to coordinate the beginning, and radius of the x and y-axis, while the z = 0. Because the ray that affects the circle from the point source of light is a tangent to the circle. We need to find a part of the sphere, which is enough for the formation of reflection, and he is determined with intersecting points from tangents from the point source of light and the sphere (i.e. the circle which we observe). As we point out that withdrawing tangent and we know the formula for a circle that is tangent, it is necessary to find the right equation of tangent (in this case, the two tangents).

The equations of tangents are obtained as a solution of the system of equation (7).

$$\begin{gathered} y = kx + l \\ x^2 + y^2 = r \end{gathered} \tag{7}$$

Tangent formula (8) is found if we consider the condition that some line is a tangent to the circle centered at the point O [15].

$$\begin{gathered} k_{1/2} = \pm \frac{\sqrt{-4(1-x_i^2)(1-(y_i-d)^2)}}{2(1-x_i^2)} \\ l_{1/2} = y_i - k_{1/2} x_i \end{gathered} \tag{8}$$

Characteristic points of the reflection are given with (9):

$$x_{1/2} = -\frac{\left(k_{\frac{1}{2}}(l_{1/2} - d)\right)}{\left(1 - k_{1/2}^2\right)}$$
$$y_{1/2} = k_{1/2} x_{1/2} + l_{1/2} \tag{9}$$

Then the intersecting point of the tangent and the circle is found as a solution of the equation of circle and equations tangent of the circle because the intersecting point is at the same time and on the circle and the tangents, which means that it satisfies both formulas.

Therefore, the algorithm to be followed when creating a reflection of the sphere is as follows:

1) to find the equation of the tangent from the light source to the circle belonging to the sphere of the x, y plane, where z = 0;

2) to find common points that belong to tangent and circle.

3) to find a symmetric beam or reflected beam for the intersection points (in the same way as in the circle), as well as with the center of the intersecting circle.

There are two cases: when the light source is just below the sphere and when the light source is right/left are shown in Figure 4.

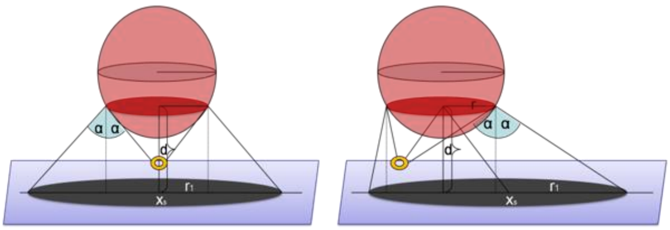

Fig. 4. A reflection of the sphere on the plat surface using the point light source: left) xi=xp=0 right) xi≠xp

IV. EXPERIMENTS

To confirm the validity of practical formulas and check the speed and the reality drawing shadows created a C++ application that uses OpenGL. The application considers the above limitations. The application has the following features:

Changing of a shadowed object, which could be a circle or sphere (keys K, L)

Changing the position of the camera, by increasing or decreasing x, y, and z coordinates (keys Y, X, C, A, S, D)

Changing the position of the point light source, by increasing and decreasing x and y coordinates (keys V, B, N, M).

The results for each element are given with the following screenshots (Fig. 5). The subject of future research will be troubleshooting the glare of the light source where y coordinate of the light source is less than y coordinate shadowed object, i.e. when the light source is below the shined object.

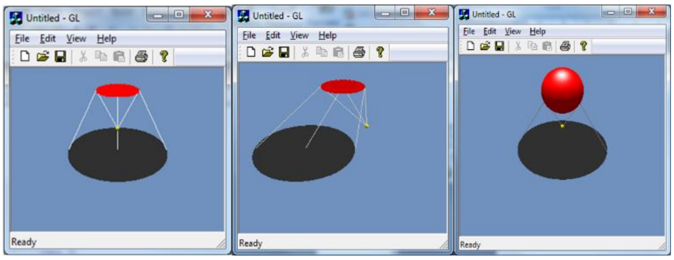

Fig. 5. The implementation of shadows in the OpenGL C++ application

V. CONCLUSIONS

By projecting all points on the surface slows the drawing of the reflections. Therefore, it is enough to find the minimum number of characteristic points, and the real reflection will not be disturbed, and its rendering will be easy and cheap.

In the future, the focus will be on the finding methods for making reflections remaining primitives that are commonly used. And other cases will be analyzed: the case when the object can move, what happens if there are more sources of light or more objects in the scene, or if the surface is not flat.

After analyzing all the conditions in which the object can be found, the output should be a unique and efficient technique for forming real OpenGL specular reflections.

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