VISUALIZATION OF THE DEFORMATION OF PLANET DUE TO TIDAL FORCES USING XNA GAME PROGRAMMING NETWORK

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Sourabh
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The Undersigned Faculty Committee Approves the

Thesis of Sourabh:

Visualization of the Deformation of Planet Due to Tidal Forces Using XNA
Game Programming Network

Kris Stewart, Chair
Department of Computer Science

Joseph Lewis
Department of Computer Science

Calvin Johnson
Department of Physics

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DEDICATION

I dedicate this thesis to my beloved mother and father who have been a constant inspiration for me throughout my life.
ABSTRACT OF THE THESIS

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by
Sourabh
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Tidal forces on a body are governed by various forces that act on it. The result of these net forces is the formation of tides. Tidal studies are an important part of the curriculum of high school students and beyond, according to the California State Department of Education (CSDE), which sets the standards for all schools in the State of California. Tidal forces are also an important branch of study in astrophysics and mathematics. Thus, it is very important that such important concepts are presented for students in a clear and concise manner for complete understanding of the topic conceptually.

This thesis aims in helping high school students to understand the basic concepts of tidal forces in a visual manner in an interactive environment.

XNA game programming framework was used to create the tidal simulation. This framework helps in the successful incorporation of 2D and 3D designs in a simple manner, and helps the game be more interactive and interesting.

In this simulation, the user begins with a title screen with the title of the game and the options of Play Demo, Instructions and Exit. The Instruction screen gives precise control instructions to the user on how to operate the simulation. The Play Demo option leads to the actual simulation page, which has a planetary body in the center, with a mass revolving around it. As you move the mass around/closer/further from the planet, tidal forces, which lead to the deformation of the planet, are simulated accordingly. Thus, the user is able to visualize the effect of tidal forces effectively.

Overall, this project aims to provide a visual, interactive and game-based approach that can be successfully incorporated into an academic setting.
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CHAPTER 1

INTRODUCTION

1.1 HISTORY

The word “tide” originates from the Germanic word, “tidiz”, meaning "a division of time", relating to the way ocean tides rise and fall over periods of time. Ancient civilizations have developed around oceans and knowledge of the behavior of these water bodies has thus existed since olden times. Over generations, the effect and behavior of tides has been closely studied and documented, and various theories have been recorded to predict the tidal pattern. As navigation and waterways developed, seafarers observed a relationship between the tidal pattern and the Moon, but the reason behind the relationship was unknown. One of the earliest evidence for the existence of prediction of tides was the discovery of a tidal dock off the Cambay coast in the state of Gujarat, India, dating roughly around 2000B.C. A tidal dock is a large-sided water basin, which opens to the sea, and was equipped to berth and dock ships. The ancient Roman, Greek and Babylonian civilizations were also observant of the tidal patterns with the voyages of Pytheas of Marseille to northern Europe and of Alexander the Great to the mouth of the Indus river on the Arabian Sea coast (330-324 B.C) [1]. Dicaearchus, the ancient Greek philosopher and disciple of Aristotle, noticed the influence of Sun and Moon on terrestrial tides. The Chinese were the first to keep written records about ocean tides and by the 4th century had developed an understanding that Moon was a factor in the occurrence of tides.

It was centuries later, however, that the one of the most significant discoveries in the understanding of tidal forces was made by Sir Isaac Newton (1642-1727). He explained the mathematical theory on tides under gravitational pull from the Sun, Moon and Earth. The book, Philosophae Naturalis Principia Mathematica, written by Newton is one of the great milestones in scientific history. The three books explained the concept of universal gravitational attraction between massive bodies. This was justified by Newton using calculations and geometric reconstructions which accorded with the then observed phenomena in the solar system, including the Kepler’s laws of planetary motion. Kepler's
laws stated that: (1) The orbit of every planet is an ellipse with the Sun at one of the two foci, (2) A line joining a planet and the Sun sweeps out equal areas during equal intervals of time, (3) The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit. Newton’s calculations corresponded with these three laws.

Some of Newton’s deductions were incorrect, due to certain misconceptions that existed at that time about the vertical forces on the surface level of the ocean. Newton’s theories were undoubtedly revolutionary, however, similar to many pioneering ideas, they were in need of refinement and to be tested to real measurements. Daniel Bernoulli, a French mathematician, published a prestigious essay in 1840 titled “The flood and the ebb of the sea”, which won a prize jointly with essays by two other physicists. These three memoirs on tides encompassed everything that was done on this subject between Newton’s publications and Laplace’s equations [2]. Laplace’s tidal equations have served as the foundation for future scientists to study the physical and mathematical concepts of tidal forces known today [3].

1.2 BACKGROUND

Oceans cover about 70% of the Earth’s surface and contain roughly 97% of the Earth's water supply. More than 50% of the Earth’s population lives within 100 miles of the oceans and has an effect on the daily dynamics of the coastal zones. They serve many functions, especially influencing the weather and temperature. They moderate the Earth's temperature by absorbing incoming solar radiation (stored as heat energy). One of the more important influences is the role of the oceans in the generation of periodic tides.

Tides are the periodic vertical movement of water on the Earth’s surface. The tidal forces arise from the gravitational attraction of bodies external to the Earth. Thus, gravitational forces are responsible for the rise and fall of the ocean's tides all over the world. The two main celestial bodies influencing the tidal forces are the Sun and Moon. The gravitational pull of a body is directly proportional to its mass, thus the Sun has an advantage over the Moon in terms of the strength of the force that it exerts. However, the Sun is about 380 times farther to Earth than the Moon. Therefore, the Moon exerts a greater control over the Earth’s tides than the Sun, even though its mass is comparatively much smaller than the Sun. The Sun's gravitational force on the earth is only about 46 percent that of the Moon.
These external forces exerted by the Sun and the Moon are called as tide-producing, or so-called "tractive" forces [4].

Another force that contributes to the formation of tides is the gravitational force that is exerted by the Earth itself. At the Earth’s surface, its own gravitational force acts in the inward direction towards the center of mass, which confines the ocean water to the surface of the Earth.

Thus, the tidal forces are a result of the net effect of: (1) the force of gravitation exerted by the Moon and Sun on the Earth and (2) the force of gravitation of the Earth itself. Both the Moon and the Earth are constantly moving through space. The Moon revolves around the Earth, the Earth revolves around the Sun and the Earth also rotates on its own axis. Thus, the distances between the three bodies and their relative positions to one another constantly change. Since the Earth spins on its own axis, water is kept balanced on all its sides through centrifugal force. The Moon's gravitational forces are strong enough to disrupt this balance by accelerating the water towards the Moon, which causes the water to 'bulge.' The areas of the Earth where the bulging occurs experience high tide, and the others are subject to a low tide. Figure 1.1 [5] illustrates the tidal “bulge” on the earth’s surface with respect to the gravitational pulls of the Moon and the Sun. However, the Moon's movement around the Earth and the Earth’s revolution around the Sun means that the effects of its forces are in motion as well, and as it encircles our planet, this bulge moves with it. Thus, the tides are dependent on the complex combination of the various forces that work together and result in a net force, as illustrated in Figure 1.1. Depending on this distance and position, tides may be higher or lower, and tidal currents may be stronger or weaker [6].

The Moon's orbit brings it in closer proximity to our planet and closest distance within a Moon cycle is called **perigee**. At perigee, its gravitational forces can increase by almost 50%, and this stronger force leads to high tides. Similarly, when the Moon is farther away from the Earth and furthest distance is called **apogee**, the tides are not as strong [7] (see Figure 1.2 [8]).

Spring tides and neap tides result from the alignment of the Sun and the Moon relative to the Earth. Spring tides occur when the Earth, the Sun, and the Moon are in a line. Neap tides are especially weak tides and occur when the gravitational forces of the Moon and the Sun are perpendicular to one another with respect to the Earth [9] (see Figure 1.3 [10]).

The Moon rotates around the Earth in 24 hours. However, the Earth takes slightly longer than 24 hours to line up again exactly with the same point on the Moon. The Moon revolves in its orbit around the earth with an angular velocity of approximately 12.2° per day, in the same direction in which the Earth is rotating on its axis with an angular velocity of 360° per day. In each day, therefore, a point on the rotating Earth must complete a rotation of 360° plus 12.2°, or 372.2°, in order to "catch up" with the Moon. Since 15° is equal to one hour of time, this extra amount of rotation equal to 12.2° each day would require a period of time equal to 12.2°/15° x 60 min/hr., or 48.8 minutes Thus, the timing of high tides is staggered throughout the course of a month, with each tide commencing approximately 24 hours and 50 minutes later than the one before it. This period of 24 hours and 45 minutes is termed as the “tidal day” [11].

While the influence of the Moon and the Sun on the formation of tides and tidal forces is significant, other small factors also play a role in this process. For instance, the shape of the coastline can affect the tidal current. When tidal currents hit wide continental margins, the height of the tides can be magnified. Conversely, mid-oceanic islands not near to the continental margins typically experience very weak tides.
Local wind and weather conditions also can affect tides. Strong offshore winds move water away from the coastlines, exaggerating low tide effects. Onshore winds may act to move water onto the shoreline, causing higher tides than normal. High-pressure conditions depress sea levels, leading to clear Sunny days with exceptionally low tides. On the other hand, low-pressure conditions that resulting cloudy, rainy weather are associated with higher than predicted tides [12].

1.3 Need for Study

Tidal forces and the laws of gravitation are one of the principal concepts of astronomy and physics. Tidal studies help in safe navigation and coastal development. Scientists measure the various parameters related to the tidal outflows, the understanding has important implications in our daily lives. Seafarers require the knowledge of the height and time of tides as well as their speeds to navigate their ships safely through the shallow ports, estuaries, etc. Tidal data is also critical for recreational boating, fishing and other coastal activities. Weather changes are also dependent on tidal changes to an extent. Engineers need the data to monitor fluctuating tide levels for engineering projects like construction of bridges and docks.

A simulation, which mimics the basic laws of gravitation and tidal forces of attraction between two celestial bodies, is useful in explaining some of these more complicated concepts to high school students. According to the Standards Handbook for California Public Schools published by the California State Department of Education (CSDE)’s, students in grades 9-12 are supposed to be equipped with basic knowledge of physics such as motions and forces including Newton’s laws of gravitation. The handbook states that, “Students know the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth,” among other important related concepts [13]. Thus, a simulation like this can be a useful aid for educators to help students understand these important concepts in physics and astronomy, in a simplified and interactive manner.

1.4 XNA Game Programming Framework

XNA is a programming tool developed by Microsoft for development of interactive programing that runs independent of its development environment. It is a popular
programming language among game developers for both PC and XBOX 360 consoles and Windows. The XNA framework allows for the creation of both 2D and 3D games. This programming tool helps in reducing a programmer’s worries by not having to switch between different programming environments to code games for multiple platforms. Thus, if a person who has been playing his/her favorite game on a PC for a longtime, now wants the access to the same game on their gaming console, this feat can be achieved using the XNA game-programming network.

XNA is based on the .NET framework and thus knowledge of the Visual Studio environment and basic C# language is enough to adapt to this framework. It can be used to not only create a drawing or a text on screen, but also render a 3D model on the screen. This flexibility is a great asset to create a variety of simulations/games. I have used XNA to create a tidal force simulation for the use of high school students to understand the concept of tidal forces between two bodies with gravitational forces of attraction. XNA is free for use for education-related purposes [14].

Thus, I chose to work with XNA for my project for its ease of use and for the flexibility that it provides me a programmer to develop a simulation for educational purposes.
CHAPTER 2

LITERATURE SURVEY

2.1 PREVIOUS EXPERIMENTS

A number of mathematical models and simulation systems have been used to recreate tides and the tidal forces. These present models range from interactive computer resources developed for upper grade and high school students for the purpose of explaining the concept of tidal forces to graduate student dissertations with complex simulations constructed using numerical and computer programming methods [15, 16].

Stine Poulsen, a graduate student in Geophysics from the University of Copenhagen based his dissertation to study the tidal deformation of Solid Earth using MATLAB. He developed two Earth models (homogenous earth model and the layered earth model) assuming that the Moon is the only attracting body and that Earth and Moon have a stationary relationship. He used the two-dimensional steady state version of Navier’s equations of motion to numerically solve the tidal deformation of the Earth. He depicted the Earth’s response in his models by radial and tangential displacement fields. An example of one of his models is illustrated in Figure 2.1 [17]. Figure 2.1 (a) shows the radial displacement field, Figure 2.1 (b) shows the tangential displacement field and Figure 2.1 (c) shows the total displacement field. The displacements are given for a quarter sphere, where the bottom left corner is the center of the Earth, top left corner is the North Pole, and bottom right corner is the equator [17].

Ingo Berg, a web developer has developed an Java applet demonstrating the tidal effects on Earth due to the gravitational pull of the Moon for every point on the Earth’s surface. Using the applet, he calculates the force vector resulting from the gravitational pulls of the earth and the Moon and the centrifugal force for every point on the Earth’s surface pointing away from a common center of mass. This is the force driving the water from one side of the Earth to the other. Since the Sun is much more heavier than the Earth, he has neglected the gravitational pull of Earth on it. A screenshot of his applet is depicted in Figure 2.2 [18]. In Figure 2.2, the yellow lines are the vectors of the tidal forces caused by the Sun,
Figure 2.1. Homogenous Earth model as shown by S. Poulsen: (a) radial displacement field (b) tangential displacement field (c) total displacement field. Source: S. K. Poulsen, *Tidal Deformation of Earth: A Finite Difference Discretization*, University of Copenhagen, Copenhagen, Denmark, 2009.
Craig Brubaker from Union College, NY developed an application using Java, which could be used as a demonstration to understand the effect of orbital cycles on tidal forces for introductory level geology courses. His simulation models the orbits of the Moon and the Earth, calculates the resultant tidal forces, and graphically displays the tidal bulges that are produced. For user input the simulation accepts current positions in each of the seven following cycles: solar tide, solar tide sub solar latitude, earth orbit/eccentricity, lunar tide, lunar orbit/eccentricity, precession of the lunar orbital ellipse, and precession of the lunar orbital plane. Figure 2.3 [19] illustrates the application and how the user interface is.

Dr. Eugene Butikov, Professor of Physics from St. Petersburg State University, Russia has a vast array of simulations on oceanic tides, physics of oscillations, pendulum with square-wave modulated length, planets and satellites etc. using Java applets. The Oceanic Tides simulator shows the tides generating forces that arise on the Earth due to the gray lines are vectors of the tidal forces caused by the Moon (twice as strong as the Sun) and adding both these forces derives the gray envelope [18].
gravitational field of the Moon. The generated tidal forces in the simulation lie in the geocentric reference frame that rotates together with the Earth. The simulation also shows the stationary tidal wave which is generated by forces in a simplified model of the Earth that is covered everywhere with a water envelope of equal depth as shown in Figure 2.4 [20].

2.2 WHY CHOOSE XNA?

XNA game programming framework developed by Microsoft helps in the development of video games for multiple platforms like Windows PC and Xbox 360. It helps in 2D and 3D rendering of models [14]. However, apart from amusement, it can also be
useful in the development of games, which are a form of interactive media for a purpose other than mere amusement, otherwise known as “serious games”. Serious games can be used as tool to diversify teaching mediums by expanding the limited avenues a teacher has to convey information to his/her students [21].

In this project, I have attempted to employ a similar idea to develop a simulation which can be used by high school students to understand the gravitational forces of attraction between two bodies in space, for instance the Earth and its satellite, the Moon, and how these forces of attraction affect the tides and tidal forces. While making of a commercial game using the traditional production method is tedious, Microsoft XNA helped me to achieve my target tidal simulation in a few weeks. Also, Microsoft XNA is programmed in C#. XNA is also free to be used by developers for all education related purposes. For all these reasons, I chose to work with the XNA game-programming framework.

The development of this simulation as part of my dissertation and other similar simulations on a variety of topics by others using XNA illustrates the fact that educators, without expert knowledge, can partner with programmers and use the latest programming tools to create useful content which can be incorporated to be a part of secondary and higher education curriculum.
CHAPTER 3

ANALYSIS OF TIDAL FORCES

In order to build a simulation for the effect of tidal forces on the deformation of a planet in XNA, it is important to first derive the equation that quantitates the effect of the said tidal forces on an ellipsoidal planetary body. In this chapter, the equation that will help to determine the tidal bulge on the ellipsoidal body due to tidal forces has been derived. This final equation (i) is then used as a key controlling equation for XNA implementation.

At the surface of the Earth, its gravitational force acts inward towards its center of mass, which keeps the oceans bound to the Earth’s surface. Along with the Earth’s gravitational force, the gravitational force of the Moon also acts externally on the Earth’s oceans. These external forces are known as the so-called “tractive forces”. The net effect of these two superimposed forces, the former acting inward and the latter acting outward, gives rise to the tidal forces, resulting in formation of tides.

Principal Laws of Gravitation and Tidal forces are as follows:- Newton’s Universal Law of Gravitation states that,

\[
F = \frac{G(mM)}{d^2}
\]

Where,

- \(F\) = force acting between the two bodies
- \(m\) = mass of Moon
- \(M\) = mass of Earth
- \(G\) = gravitational constant
- \(d\) = distance between their centers

The tidal force equation is a derivative of the Newton’s law of gravitation stated above. The tidal force is the difference between the tidal forces at two different distances. This differential force is important because the outer edge of the mass is pulled relative to its center of mass. If equal forces had pulled between them, there would not have been any deformation (see Figure 3.1 [22]).
Gravitational force at the center of the mass is:

$$ F = \frac{G (mm)}{d^2} $$

Gravitational force at the outer surface of the mass is:

$$ F = \frac{G (mM)}{(d+\Delta r)^2} $$

Where,

$\Delta r$ = radius of the mass:

As stated previously, the difference between the forces at the two different distances would result in the tidal force, $F_{\text{tidal}}$, which would be as follows:

$$ F_{\text{tidal}} = \frac{GmM}{d^2} - \frac{GmM}{(d+\Delta r)^2} $$

Where, $\Delta r<< d$
Since $\Delta r \ll d$

$$F_{\text{tidal}} = \frac{2GmM_r}{d^3}$$

This is the tidal force equation [22].

**Tidal Deformation:** my project aims to simulate the changes in tides due to the Moon’s gravitational pull, and the resulting changes are termed as “tidal deformation”. Since the Moon-Earth gravitational forces are twice than those of the Sun-Earth, only the interactions between the Earth and Moon are examined while the effect of Sun’s forces are omitted. Thus, tidal deformation of Earth resulting only from the combination of the gravitational forces between Earth and Moon [23].

Let “$d$” be the distance between Moon and Earth; assume it is along x-axis as shown in Figure 3.2. Then the effect of the gravitational force of the mass of Moon “$M_L$” on test mass “$m$” at location ($x, y, z$) relative to the center of the Earth is:

$$\frac{GmM_L}{\sqrt{(d+x)^2+y^2+z^2}}$$

![Figure 3.2. Figure depicting relative positions of masses $M_E$, $M_L$ and $m$.](image)

Assuming $x, y, z$ are much smaller than $d$, we can expand the equation in Taylor series:

$$\frac{GmM_L}{\sqrt{(d+x)^2+y^2+z^2}} = \frac{GmM_L}{d} + \frac{GmM_L}{d} \frac{x}{d} + \frac{GmM_L}{d} \left( \frac{x^2}{2d^2} - \frac{y^2}{2d^2} - \frac{z^2}{2d^2} \right)$$

When we include the centrifugal potential from the motion of the Moon around the earth, the term linear in $x$ cancels out, and the constant term is just that, a constant.
Now include the potential along the surface of the earth:

\[
\frac{GmM_E}{\sqrt{x^2 + y^2 + z^2}}
\]

Now the distorted surface of the Earth x is given equipotential surfaces, this is, surfaces of constant:

\[
\frac{M_E}{\sqrt{x^2 + y^2 + z^2}} d \left( \frac{x^2}{2d^2} - \frac{y^2}{2d^2} - \frac{z^2}{2d^2} \right) = \text{Constant}
\]

Assuming the Earth is a sphere with a spherically symmetric mass distribution, the undisturbed gravitational potential of Earth’s surface will be, \( \frac{GM}{R} \)

At a point P that is located “p” distance from the center of the sphere, the Earth’s gravitational potential is \( \frac{GM}{p} \).

By reducing the gravitational constant we obtain:

\[
\frac{x^2}{R^2 \left( 1 + 2\mu \frac{R^3}{d} \right)} + \frac{y^2 + z^2}{R^2 \left( 1 - \mu \frac{R^3}{d} \right)}
\]

Where \( \mu \) is the ratio of the masses of the gravitating body to the mass of the planet. The equation of a conventional biaxial ellipsoid is [24]:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1
\]

Thus, applying the above equation of the biaxial ellipsoid to my equation, we get:

\[
a = \left( 1 + \mu \frac{b^3}{d^3} \right)R, b = c = \left( 1 - \mu \frac{b^3}{d^3} \right)R \quad [i]
\]

Equation (i) is the key controlling equation that was used for XNA implementation. From this we can calculate the tidal bulge on the planet caused by the gravitational pull of the Moon [25].

When \( a = b = c = 1 \), the planet shape would be spherical, and in this case, no tides would occur. Smaller the distance between mass and planet, higher the effect of tidal forces.
The planet will thus deform its shape according to the change in distance between the two bodies.
CHAPTER 4

CODE DESIGN AND IMPLEMENTATION

4.1 OVERVIEW OF THE IMPLEMENTATION

This project can be seen as a 3D game simulation which can be applied in the learning environment for high school students and help them understand the concepts tides and the deformation of the planet under tidal forces. As illustrated in Figure 4.1, the basic framework of the game is such that it essentially has a splash screen that displays the name of the project and as set of instructions as a guide as to how to use the simulator for the user.

![Flowchart of the simulation.](image)

The splash screen has a preview of a mass and a planet separated by a certain distance. The user can change the mass of object and planet, and can increase or decrease the distance between the mass and the planet. The user is also able to control the camera angle and zoom in and zoom out. User can change either of their masses and the tidal forces will change according to the set parameters.
4.2 Code Design

In order to build this simulation, the Game loop strategy was put into use. There is a particular order in which the functions are called. Figure 4.2 shows a basic diagram illustrating how game loop exactly works.

![Figure 4.2. Flowchart of game loop implementation.](image)

4.2.1 Initialize()

First, the game object’s Initialize() would be called. The Initialize() function is where the code is put which initializes the default or starting values for particular property variables or private variables.

Below is the code for Initializing code for Planet that is ellipsoidal in shape.

```csharp
private void InitializeEllipsoid(int Stacks, int Slices, int Radius, out VertexPositionNormalTexture[] vertices, out int[] indices, bool sphere)
{
    float M1 = planetMass * 1000000; // planet mass in kg
    float M2 = objectMass * 1000000000; // object mass in kg
    float d = distance * 1000000; // distance in meters
    float R = 100000; // radius in meters(100km)

    float a = (float)Math.Sqrt(R * R * (1 + 2 * (M2 / M1) * ((R * R * R) / (d * d * d))));
    float b = (float)Math.Sqrt(R * R * (1 - (M2 / M1) * ((R * R * R) / (d * d * d))));
    float c = b
    float scale = Math.Max(a, b) / 2;
}```
Below is the code for initialization of forces that are applied on the planet.

```csharp
private void ApplyForce()
{
    float G = 6.673f / 100000000000; // gravitation const
    float M1 = planetMass * 1000000; // planet mass in kg
    float M2 = objectMass * 1000000000; // object mass in kg
    float m = 1; // point on surface mass in kg
    float d = distance * 1000000; // distance in meters
    float r = 100000; // radius in meters(100km)

    Vector3 mc = Vector3.Normalize(objectPos) * d; // object position
    Vector3 pc = new Vector3(0, 0, 0); // planet position

    float Fg = (G * M1 * m) / (r * r);
    float Ft = (1.5f * G * M2 * m * r) / (d * d * d);
}
```

### 4.2.2 Load Content()

Next, the game object’s Load Content function would be called. This function enables us to load content into memory which the game can use like sprites and custom game objects.
### 4.2.3 Update()

Once the Load Content() is called, following that, the Update() and Draw() are called one after the other, in a recurring continuous loop, as illustrated in Figure 4.2.

```csharp
protected override void Update(GameTime gameTime)
{
    if (lastScroll != ms.ScrollWheelValue)
    {
        if (newState.IsKeyDown(Keys.Left) ||
            newState.IsKeyDown(Keys.RightShift))
        {
            camera += ((lastScroll - ms.ScrollWheelValue) / 120) *
                Vector3.Normalize(camera);
            basicEffect.View = Matrix.CreateLookAt(camera, Vector3.Zero,
                Vector3.Up);
        }
        else
        {
            if (lastScroll - ms.ScrollWheelValue > 0)
            {
                objectPos += Vector3.Normalize(objectPos);
                distance += 10;
            }
            else
            {
                objectPos -= Vector3.Normalize(objectPos);
                distance -= 10;
            }
        }
    }
}

lastScroll = ms.ScrollWheelValue;

// each 50ms updating ellipsoid shape
if (gameTime.TotalGameTime.Milliseconds % 50 == 0)
{
    InitializeEllipsoid(50, 50, 2, out planetVertices, out planetIndices, false);
}
```
MouseState ms = Mouse.GetState();
    if (ms.LeftButton == ButtonState.Pressed)
    {
        if (mouseX != 0 && mouseX != ms.X)
        {
            camera = Vector3.Transform(camera,
                Matrix.CreateRotationY((mouseX - ms.X) > 0 ? 0.1f : -0.1f))
        }
        mouseX = ms.X;
    }

4.2.4 Draw()

protected override void Draw(GameTime gameTime)
{
    GraphicsDevice.Clear(Color.Black);

    RasterizerState rasterizerState1 = new RasterizerState();
    rasterizerState1.CullMode = CullMode.None;
    graphics.GraphicsDevice.RasterizerState = rasterizerState1;

    Below is the code for drawing the ellipsoid planetary body:

    basicEffect.LightingEnabled = true;
    basicEffect.VertexColorEnabled = false;
    basicEffect.TextureEnabled = true;

    basicEffect.World = Matrix.Identity;

    foreach (EffectPass pass in basicEffect.CurrentTechnique.Passes)
    {
        pass.Apply();
        if (drawSphere)
            graphics.GraphicsDevice.DrawUserIndexedPrimitives<
                PrimitiveType.TriangleList, planetVertices, 0, planetVertices.Length, planetIndices, 0, planetIndices.Length / 3);
    }
Below is the code to implement the mass’s shape.

```csharp
basicEffect.World = Matrix.CreateTranslation(objectPos);
basicEffect.LightingEnabled = true;
basicEffect.VertexColorEnabled = false;
basicEffect.TextureEnabled = false;

foreach (EffectPass pass in basicEffect.CurrentTechnique.Passes)
{
    pass.Apply();
    graphics.GraphicsDevice.DrawUserIndexedPrimitives<VertexPositionNormalTexture>(PrimitiveType.TriangleList, objectVertices, 0, objectVertices.Length, objectIndices, 0, objectIndices.Length / 3);
}
```

### 4.2.5 Unload Content()

This function is called at the exit point of the game.

### 4.3 Resulting Screenshots in XNA

In this section, I present the resulting screen shots of my simulation. These screen shots depict the deformation of the planet deform under the influence of tidal forces.

I would like to mention here that for the purpose of my simulation, I consider a planet, which has only water on its surface, in order to consider the maximum effect of the tidal forces.

#### 4.3.1 Title Screen

Figure 4.3 shows a screen shot that represents the cover page, which has the name of the game, followed by 3 options for user to select. The 3 options are: (1) Play Demo (2) Instructions (3) Exit.

#### 4.3.2 Instruction Screen

By selecting the instruction tab user will see a different slide, which has information about controls, which will help user to understand how to use this demo. Figure 4.4 shows the instruction slide.
Figure 4.3. Title screen of the game.

Figure 4.4. Instruction screen of the game.

Figure 4.5 is a screen shot shows the mass and planet separated by a fixed distance, where the shape of planet is spherical. As shown in previous chapter this will be the case of no resultant tides, where $a = b = c = 1$.

As the distance between object and planet decreases, the planet will start to deform its shape under the effect of tidal forces. Figure 4.6 shows the distance between planet and
Figure 4.5. Position of the object and the planet in the case of no tide.

Figure 4.6. Effect of the tidal force on the planet on account of decrease in distance between the two masses.
object is decreased by 100Mm, resulting in the deformed planet shape by putting values in following equations.

\[
a = \left(1 + \mu \frac{x^2}{R^2}\right)R, \quad b = c = \left(1 - \mu \frac{x^2}{R^2}\right)R
\]

As the distance decreases, there is increasing effect of the tidal force on the planet, which causes planet to deform its shape. Figure 4.7 shows the distance between planet and object is decreased by 50Mm. This is the maximum effect of tidal forces.

![Figure 4.7. Maximum effect of tidal forces on the planet at a distance of 50mm.](image)

However, there is an exception in the simulation. As we move the object closer to the planet, at a certain point, the planet will disappear from the computer screen as shown in Figure 4.8.
Figure 4.8. Disappearance of planet beyond a limited distance.
CHAPTER 5

CONCLUSION

This game represents a simulation of tidal forces using XNA game programming framework. This game can be used by students to understand the basic concepts of tidal forces between two celestial bodies. A visual representation always aids in understanding the concepts written in a textbook, so this simulation can be incorporated in the syllabus to make learning more interactive and fun. This simulation provides a simple and effective way to get across some of the more complicated concepts related to tidal forces. Also the fact that this game can be used on Xbox consoles, adds another layer of accessibility to the game by increasing the number of media platforms that can be used to access the simulation.
CHAPTER 6

FUTURE WORK

This game was built using the XNA game-programming framework 4.0. There are many different features that can be added to the simulation in order to make it more user-friendly and interactive. Some of these include:

- Use of better graphic design and 3D models to enhance the current simple layout of the simulation, so that it could resemble the planetary massed and outer space visually.

- Since this simulation is mainly aimed towards students, information about tidal forces could be incorporated in the game. Based on what they read in the game, quizzes could be included at the end of the game in order to test the depth of their understanding of the topic. In this way, it could be included in a lab course as an online assignment or something of a similar nature.

- Audio instructions and narrations can also be added to aid the user in order to navigate the game.

- In this simulation, the Sun’s tidal forces have not been considered, due to their minimal effect as compared to the Moon. However, the effect of the Sun’s gravitational forces could also be incorporated to perfectly match the actual conditions in nature.

- The Earth not only rotates around the Sun, but also revolves around its own axis. The effect of the latter was not considered in my simulation, and thus could be incorporated in a future version.

- Enable the game to be exported into Xbox consoles and Kinect so that the user has choice to play it either on a PC or a console.

- Other parameters related to tidal forces like tidal potential and rates of tidal currents could also be incorporated into the game for a more in-depth analysis of the topic.
REFERENCES


