INTERNATIONAL ISLAMIC UNIVERSITY CHITTAGONG

Department of Computer Science Engineering

Project Report

A Dynamic 3D Simulation of the Greenhouse Effect using OpenGL and C++

Course Code & Name

CSE-4742

Computer Graphics Lab

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Abstract

This project presents the development of a real-time, three-dimensional simulation designed to visualize the fundamental principles of the Greenhouse Effect. Implemented using C++ and the OpenGL (Open Graphics Library), the system models a simplified environment, including a ground plane, an atmospheric layer (represented by the greenhouse glass), and a solar light source. The core objective is to dynamically demonstrate the heat-trapping mechanism: solar radiation (short-wave energy) entering the system, the transformation into infrared radiation (long-wave heat), and the subsequent reflection and absorption of this heat within the environment. The outcome is a powerful, interactive educational tool that utilizes computer graphics to clearly illustrate complex climatological concepts.

Acknowledgement

We wish to express our profound gratitude to our course lecturer for her expert guidance, continuous encouragement, and invaluable feedback throughout the execution of this project. Their insights were instrumental in transforming the project concept into a working simulation.

We acknowledge the global open-source community for the development and maintenance of essential tools like OpenGL and freeGLUT/GLFW, which provided the fundamental graphic libraries necessary for this visualization.

Lastly, we acknowledge the contribution and cooperation of all group members—Tasnim Showkat Diba, Naofi Azim Toishy and Iftekharunnesa Rafi—whose dedication and teamwork made this project successful.

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1. Introduction

The Greenhouse Effect Simulation is an interactive, high-fidelity computer graphics application developed using the C++ programming language and the OpenGL (Open Graphics Library) framework. In an era where global warming and climate change pose existential threats to our planet, this project serves as a bridge between complex environmental data and intuitive visual understanding.

The primary focus of this simulation is to model the Atmospheric Greenhouse Effect, a process where certain gases in the Earth's atmosphere trap heat that would otherwise escape into space. While this effect is naturally necessary to maintain a livable temperature on Earth, human activities have accelerated the concentration of these gases, leading to an imbalance.

This project goes beyond a static diagram; it creates a dynamic 3D ecosystem. It incorporates key environmental elements such as:

1. Solar Radiation Modeling: Visualizing short-wave energy entering the atmosphere from the sun.
2. Thermal Trapping: Demonstrating how long-wave infrared radiation is reflected from the Earth's surface and subsequently trapped by increased gas levels.
3. Environmental Impact Feedback: A real-time system that monitors variables like Global Temperature, Atmospheric Pressure, and Ozone Layer Integrity.

By utilizing the GLUT (OpenGL Utility Toolkit), the simulation provides a user-centric experience. Users can interactively manipulate pollution levels through keyboard inputs and observe immediate, catastrophic shifts in the environment—such as the ground losing its fertility (changing color) and the heat intensity rising. This makes the project an invaluable tool for educational demonstrations, climate change awareness, and computer graphics research.

2. Objectives

The key objectives of this project are:

- To visually simulate the working mechanism of the greenhouse effect using computer graphics.
- To provide interactive controls that allow users to manipulate sunlight intensity, gas concentration, and camera viewing angles.
- To introduce a Gas Slider UI that enables users to change CO_2 and other gas levels dynamically.
- To integrate a Temperature Indicator that shows real-time changes in atmospheric temperature.
- To create an engaging learning tool that connects computer graphics concepts with environmental science.
- To demonstrate the mechanism of short-wave solar radiation entering the atmosphere and long-wave infrared heat being trapped.
- To showcase the direct correlation between gas levels and environmental variables like Temperature, Atmospheric Pressure, and Ozone Layer health.
- To allow users to manipulate gas levels and observe immediate environmental consequences in a controlled 3D space.

3. Importance of the Project

This project is not merely a graphical model; it serves as a powerful medium for understanding the impacts of climate change and controlling environmental variables through code. The significant aspects of its importance include:

- **Interactive Learning Experience**: Rather than just reading about the Greenhouse Effect in textbooks, users can manually increase or decrease gas levels (CO2) to observe the live impact. This makes it an essential interactive tool for students and researchers.
- **Real-time Impact Visualization**: The dynamic color change of the ground (from green to scorched red/brown) demonstrates how rising temperatures adversely affect soil fertility and vegetation.
- **Atmospheric Dynamic Modeling**: Unlike standard diagrams, this project illustrates the complex relationship between Temperature, Atmospheric Pressure, and the Ozone Layer. It serves as an excellent example of modeling environmental complexity.
- **Graphical Representation of Invisible Rays**: Through the animation of solar rays (yellow) and heat rays (red), the simulation makes visible the physics of how glass or atmospheric gases trap thermal energy. It brings invisible physics into a visual space for better comprehension.
- **Predictive Alert System**: The animated arrows in the HUD (Heads Up Display) alert the user to the direction of environmental change. This functions as a basic prototype for real world environmental monitoring systems.
- **Biodiversity Representation**: The inclusion of animated Birds and Trees highlights the importance of natural balance in an ecosystem, which is currently under threat due to global warming.
- **Software Engineering Application**: This project clarifies for computer science students how to implement a state-machine (transitioning from a Question Screen to a 3D Simulation) using the OpenGL/GLUT library.

4. Key Aspects

Task	**Description**
1. OpenGL	Rendering, modeling, lighting, and animation.
2. GLUT / FreeGLUT	Window management and input handling.
3. C++	Main programming language
4. Rendering Pipeline	Utilized a Fixed-Function Pipeline to simulate heat glows, ray animations, and semi-transparent atmospheric effects.
5. Math Libraries	For transformations and camera calculations.
6. UI & Text Rendering	Integrated Bitmap Character functions to display real-time data like Temperature, Pressure and Ozone levels.
7. Code::Blocks / Visual Studio	Development environment.
8. Two-Phase Interface	Implemented a State-Machine logic: Phase 1 displays educational questions, and Phase 2 renders the interactive 3D simulation.
9. Dynamic Environment	Features a complex ecosystem including a Transparent Greenhouse, green terrain, procedural trees and bird animations.
10. Visual Feedback Loops	Real-time shade like logic where the ground color dynamically shifts from healthy green to scorch brown as heat rises.

5. Description of Important Parts of the Code

This project utilizes the OpenGL/GLUT library to create an interactive 3D simulation. The code is structured into several functional blocks: Global State Management, Coordinate Systems (HUD vs. 3D**)**, Environmental Modeling, and Input Handling.

5.1 Global State and Variable Management

The program uses several global variables to represent environmental conditions:

- **gasLevel**: Acts as the primary driver for all environmental changes.
- **temperature, envPressure, ozoneLayer**: These are derived values calculated based on the current gas level.
- **showQuestions**: A boolean flag used to implement a State Machine, controlling whether the user sees the introductory questions or the active 3D simulation.

5.2 Coordinate Systems and HUD (Heads-Up Display)

The code distinguishes between a 2D Orthographic Projection and a 3D Perspective Projection.

- **drawQuestionsHUD() & drawSimulationHUD():** These functions use gluOrtho2D. This creates a fixed 2D coordinate system on top of the 3D world, ensuring that text (Temperature, Pressure) and instructions remain at fixed positions on the screen regardless of camera rotation.
- **renderText2D()**: A utility function that iterates through character arrays and renders them using glutBitmapCharacter, allowing real-time data to be displayed as text.

5.3 Dynamic Environmental Modeling (drawEnvironment)

This section contains the core visual logic:

- **Procedural Ground Coloring**: The ground's RGB values are calculated using the temperature variable. As heat rises, the green component (g) decreases and the red component (r) increases, visually simulating soil degradation.
- **Alpha Blending for Glass**: By enabling GL_BLEND and using glColor4f with an alpha value of 0.25f, the program creates a semi-transparent effect for the greenhouse box.

- **Geometry Rendering**: Trees are constructed using a combination of glutSolidCube (trunk) and glutSolidSphere (leaves), while the Sun and Birds are rendered as spheres and line-segments respectively.

5.4 Physics Simulation and Rays (display & timer)

The simulation of the Greenhouse Effect is handled through animated rays:

- **Sunlight vs. Trapped Heat**: Yellow rays move downward from the sun. Once they reach the ground (sunRayY < 1), red "Heat Rays" are triggered.
- **Trapped Energy Logic**: The intensity and height of the red rays (heatRayY) are directly proportional to the temperature and gasLevel, demonstrating the physical trapping of infrared radiation.

5.5 Mathematical Logic and Animation (timer)

The timer() function acts as the program's heartbeat:

- **Impact Formulas**:

  $\text{Temperature}=25+(\text{gasLevel}\times 5)$

  $\text{Pressure}=1013+(\text{gasLevel}\times 12)$

  $\text{Ozone}=100-(\text{gasLevel}\times 6)$

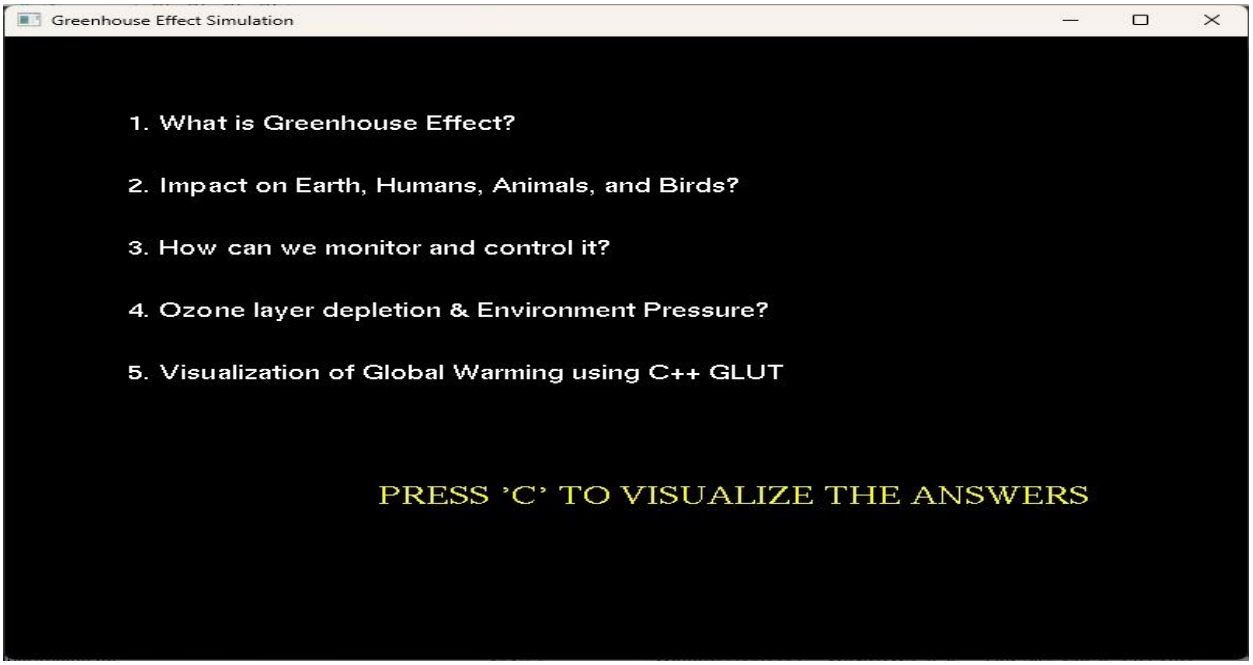
- **Animation Synchronization**: It updates the position of birds and the oscillation of the rays every 16 milliseconds (approximately 60 FPS). It also calculates the animated arrows (upper arrows/lower arrows) by comparing current values with prevTemperature, prevPressure, etc.

5.6 User Interaction (keyboard)

The program allows real-time manipulation:

- **W/S Keys**: Increment or decrement the gasLevel. This triggers a chain reaction in the timer function, updating all visual and numerical data.
- **A/D Keys**: Modify the rotationAngle, which is used in glRotatef within the display function to allow the user to orbit around the 3D model.
- **R Key**: Resets all variables to their default "Healthy" state.

6. Some Output Snapshot



1. What is Greenhouse Effect?

2. Impact on Earth, Humans, Animals, and Birds?

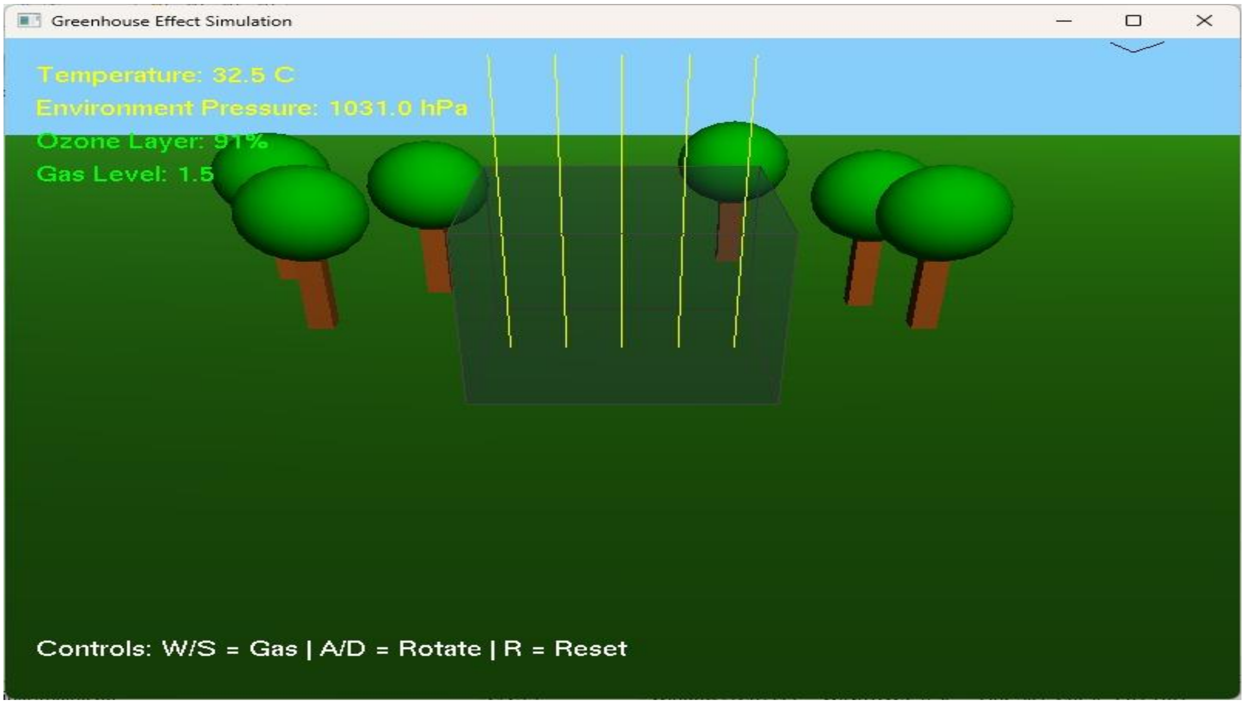
3. How can we monitor and control it?

4. Ozone layer depletion & Environment Pressure?

5. Visualization of Global Warming using C++ GLUT

PRESS 'C' TO VISUALIZE THE ANSWERS

Figure 1: Introductory Screen

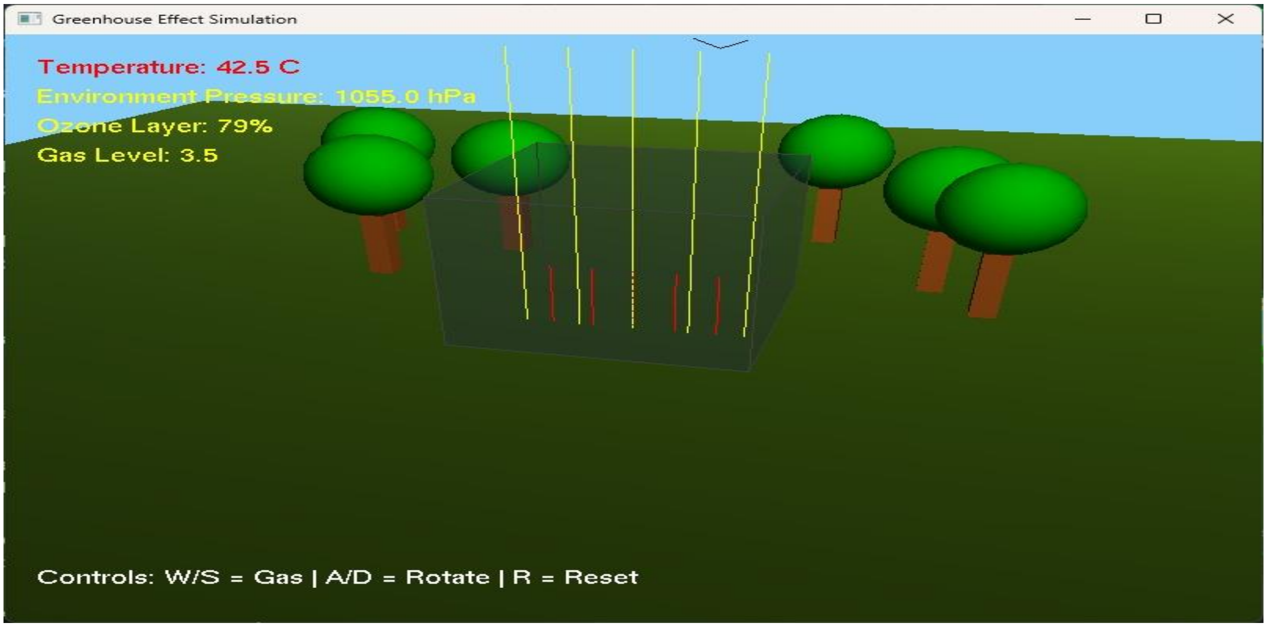


Greenhouse Effect Simulation

Temperature: 32.5 C
Environment Pressure: 1031.0 hPa
Ozone Layer: 91%
Gas Level: 1.5

Controls: W/S = Gas | A/D = Rotate | R = Reset

Figure 2: Baseline/Healthy Environment

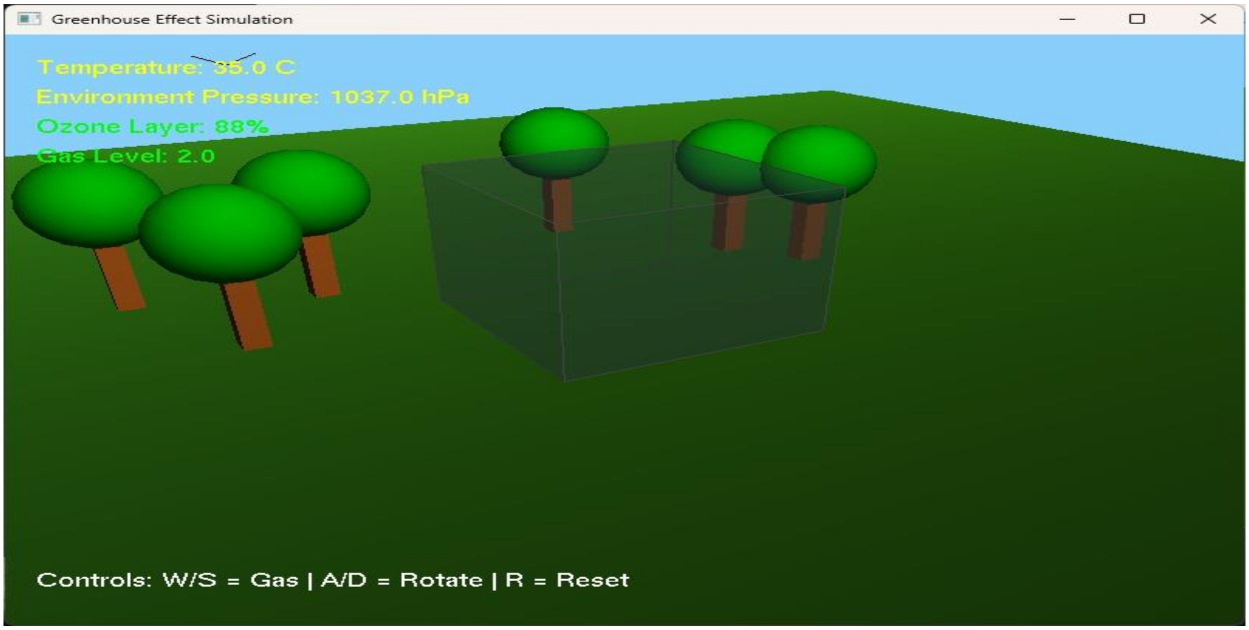


Greenhouse Effect Simulation

Temperature: 42.5 C
Environment Pressure: 1055.0 hPa
Ozone Layer: 79%
Gas Level: 3.5

Controls: W/S = Gas | A/D = Rotate | R = Reset

Figure 3: High Pollution/Critical State



Temperature: 35.0 C
Environment Pressure: 1037.0 hPa
Ozone Layer: 88%
Gas Level: 2.0

Controls: W/S = Gas | A/D = Rotate | R = Reset

Figure 4: Interactive Rotation (3D View)

7. Conclusion

The 3D Greenhouse Effect Simulation project represents a successful integration of computer graphics and environmental science. By leveraging the OpenGL/GLUT framework, this application transcends static textbook diagrams to provide a dynamic, real-time interactive experience. Through this project, several critical conclusions can be drawn:

- **Educational Impact**: The simulation proves that complex environmental phenomena, such as the trapping of long-wave infrared radiation and ozone layer depletion, are far more comprehensible when visualized in a 3D space. The "Two-Phase Interface" ensures that the user is first grounded in theoretical knowledge before witnessing the visual consequences of climate change.
- **Technical Proficiency**: From a software engineering perspective, the project demonstrates the effective use of the Fixed-Function Pipeline. Key techniques such as Alpha Blending for transparency**,** Perspective Transformations for 3D depth, and Orthographic Overlays for the HUD (Heads-Up Display) showcase a robust understanding of the graphics rendering pipeline.
- **The Power of Visual Feedback**: The implementation of Dynamic Color Indicators serves as a vital takeaway. By observing the terrain transition from a healthy green to a scorched

reddish-brown, users develop an instinctive understanding of how rising temperatures degrade global biodiversity and soil fertility.

- **Real-time Monitoring & Control**: The project highlights the necessity of human intervention in climate control. The interactive keyboard controls ('W' and 'S' keys) allow users to act as environmental managers, seeing firsthand how reducing gas levels can stabilize temperature and pressure, effectively resetting the Earth's health.
- **Future Scope**: While the current simulation focuses on core variables like temperature and ozone, it provides a scalable foundation. Future iterations could include more complex models such as melting polar ice caps, sea-level rise indicators, and more advanced lighting techniques like Shadow Mapping or GLSL Shaders for even greater realism.

In summary, this project serves as a compelling reminder of the fragile balance required to sustain life on Earth. It concludes that while the greenhouse effect is a natural and necessary process, human-induced acceleration requires constant monitoring and technological innovation to mitigate. Through this 3D simulation, the invisible threat of global warming is made visible, actionable, and educational.