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"Web-Based Virtual Interior Designer Using 3D Visualization"

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ABSTRACT: Interior design is a complex process that involves spatial planning, aesthetic arrangement, and efficient utilization of available resources. Traditional interior design approaches rely on manual sketches, 2D layouts, or expensive professional software tools, which often fail to provide real-time interaction and accurate visualization. These limitations lead to inefficient decision-making, increased costs, and unsatisfactory design outcomes.This paper presents the design and implementation of a Web-Based Virtual Interior Designer, an interactive system that enables users to create, manipulate, and visualize interior spaces in a real-time 3D environment. The system leverages Three.js, a WebGL-based JavaScript library, for rendering high-performance 3D graphics directly within a browser. The backend is developed using Node.js and Express, providing RESTful APIs for data processing and communication. User data and design configurations are stored in MongoDB, ensuring scalability and efficient data retrieval.The system supports advanced interaction features such as object selection using raycasting, translation along multiple axes, rotational transformations, and persistent storage of user designs. Secure authentication is implemented using JSON Web Tokens (JWT) to ensure data integrity and access control. Experimental evaluation demonstrates that the system achieves smooth rendering performance, low latency interaction, and efficient database operations. The proposed solution is scalable, cost-effective, and suitable for applications in interior design, real estate visualization, and architectural planning.

Keywords: 3D Visualization, WebGL, Three.js, Interior Design System, JWT Authentication, MongoDB, Human-Computer Interaction.

1. INTRODUCTION

The field of interior design has undergone significant transformation over the past few decades, evolving from traditional manual sketching techniques to advanced digital visualization tools. Interior design is not merely about arranging furniture within a confined space; it involves a careful balance between aesthetics, functionality, ergonomics, and spatial optimization. The ability to visualize how different elements interact within a space is crucial for achieving an efficient and visually appealing design. However, despite the availability of various tools and techniques, many users still face challenges in accurately conceptualizing interior layouts before implementation. This gap between imagination and visualization often leads to inefficient planning and unsatisfactory outcomes.With the rapid advancement of web technologies, especially in the domain of graphics rendering, it has become possible to create highly interactive and immersive applications directly within web browsers. Technologies such as WebGL have enabled hardware-accelerated rendering, allowing developers to build complex 3D environments that can run efficiently on standard devices. This has opened new opportunities for developing applications that were previously limited to desktop environments. In particular, the integration of 3D visualization into web-based platforms has significantly enhanced user interaction and accessibility.

Traditional interior design approaches rely heavily on 2D representations, such as floor plans and elevation drawings. While these methods provide a basic understanding of spatial arrangements, they fail to capture the depth, scale, and perspective of real-world environments. As a result, users often struggle to interpret these designs and make informed decisions. Additionally, professional design software such as AutoCAD and SketchUp, although powerful, require specialized training and are often expensive. This creates a barrier for non-professional users who wish to design their own spaces.

Another major limitation of conventional interior design methods is the lack of real-time interaction. In most cases, users must rely on static images or pre-rendered models, which do not allow dynamic modification of objects. This restricts creativity and experimentation, as users cannot easily test different configurations. The absence of immediate feedback further complicates the design process, making it time-consuming and less efficient. Therefore, there is a need for a system that allows users to interact with their designs in real time and visualize changes instantly.The emergence of web-based 3D libraries, particularly Three.js, has revolutionized the development of interactive graphical applications. Three.js provides a high- level abstraction over WebGL, enabling developers to create complex 3D scenes with minimal effort. It supports features such as lighting, shading, camera control, and object manipulation, making it an ideal choice for building interior design applications. By leveraging these capabilities, it is possible to create a system that provides a realistic and immersive design experience.The integration of backend technologies further enhances the functionality of such systems. By incorporating a server-side architecture using Node.js and Express, it becomes possible to handle data processing, user authentication, and communication between the frontend and database. MongoDB, a NoSQL database, offers a flexible and scalable solution for storing user data and design configurations. This combination of frontend and backend technologies enables the development of a full-stack application that can support real-world use cases.

1.1 Literature Review

The development of web-based 3D visualization systems has been an active area of research over the past decade, driven by advancements in graphics processing and browser capabilities. Early systems relied on plugin-based architectures such as Flash and Java Applets, which had significant limitations in terms of performance, compatibility, and security. With the introduction of WebGL, a standardized API for rendering 3D graphics within web browsers, developers gained the ability to create high-performance graphical applications without the need for additional plugins. This marked a major shift in the way interactive web applications were developed.

WebGL, developed by the Khronos Group, provides hardware-accelerated rendering by utilizing the GPU directly through the browser. While WebGL offers powerful capabilities, its low-level nature makes it complex and difficult to implement for large-scale applications. Developers must manage shaders, buffers, and rendering pipelines manually, which increases development time and complexity. As a result, higher-level libraries such as Three.js were introduced to simplify the process and provide abstraction over WebGL functionalities.

Three.js, developed by Ricardo Cabello, has become one of the most widely used libraries for 3D web development. It provides pre-built components for scene management, camera control, lighting, and object rendering, enabling rapid development of interactive applications. Several research studies have utilized Three.js to create visualization systems for education, gaming, and simulation purposes. However, most of these implementations focus primarily on graphical rendering and lack integration with backend systems for data persistence and user management.

In the domain of interior design, various software tools have been developed to assist professionals in creating and visualizing layouts. Applications such as AutoCAD, SketchUp, and Blender offer advanced features for modeling and rendering. While these tools provide high- quality output, they are often complex and require specialized training. Additionally, they are typically desktop-based applications, limiting accessibility and collaboration. This has led to the exploration of web-based alternatives that can provide similar functionality with greater ease of use.

Several web-based interior design platforms have been proposed in recent years, aiming to provide user-friendly interfaces and real-time visualization capabilities. These systems allow users to drag and drop furniture objects, modify layouts, and view results instantly. While these platforms improve accessibility, they often suffer from limitations such as restricted object libraries, lack of customization, and absence of backend integration for saving user data. This restricts their usability in real-world scenarios where persistence and scalability are essential.

Research in the field of Human-Computer Interaction (HCI) has emphasized the importance of intuitive interfaces and real-time feedback in improving user experience. Interactive systems that provide immediate visual responses to user actions are more engaging and effective compared to static systems. In the context of interior design, this means allowing users to manipulate objects dynamically and observe the impact of their changes in real time. Studies have shown that such systems significantly enhance decision-making and reduce errors.

Another important aspect of modern web applications is data management and security. With the increasing use of cloud-based systems, there is a need for efficient storage and retrieval of user data. NoSQL databases such as MongoDB have gained popularity due to their flexibility and scalability. They allow developers to store complex data structures in JSON format, making them suitable for applications involving 3D object data. Additionally, authentication mechanisms such as JWT provide secure access control, ensuring that user data is protected from unauthorized access

Despite these advancements, there remains a gap in fully integrated systems combining 3D visualization, interaction, and persistent storage, which this project aims to address.

2. PROPOSED SYSTEM

The proposed system is a **Web-Based Virtual Interior Designer** designed to provide an interactive, scalable, and user-friendly platform for interior space visualization and design. The system integrates modern web technologies to deliver real-time 3D rendering, dynamic object manipulation, and persistent data storage. Unlike traditional interior design tools, the proposed solution eliminates the need for specialized software installations and provides accessibility through standard web browsers.

The system is based on a **multi-tier architecture**, consisting of three primary layers: the **frontend layer**, the **backend layer**, and the **database layer**. Each layer is designed to perform specific functions while ensuring seamless communication with other components. The frontend is responsible for rendering the 3D environment and handling user interactions, while the backend manages data processing, authentication, and API communication. The database layer ensures efficient storage and retrieval of user data and design configurations.

2.1 System Architecture Overview

The architecture follows a **client-server model**, where the client (browser) interacts with the server through RESTful APIs. The server processes requests and communicates with the database to store or retrieve data. This separation of concerns ensures modularity, scalability, and maintainability.

- **Client Side (Frontend):** Handles UI rendering and user interaction
- **Server Side (Backend):** Processes requests and manages logic
- **Database (MongoDB):** Stores user and design data

2.2 Detailed System Modules

2.2.1 User Authentication Module

This module is responsible for managing user identity and ensuring secure access to the system. It provides functionalities such as user registration, login, and session management.

- Passwords are encrypted using hashing algorithms
- JWT is used for secure session handling
- Token-based authentication ensures stateless communication

The module ensures that each user has access only to their own design data, thereby maintaining privacy and data integrity.

2.2.2 3D Visualization Module

The 3D Visualization Module is the core component of the system, responsible for rendering the virtual environment. It is implemented using Three.js, which provides an abstraction over WebGL.

This module performs the following tasks:

- Scene initialization
- Camera configuration (perspective view)
- Lighting setup (ambient and directional lights)
- Creation of floor and grid system
- Rendering loop for continuous updates

The use of hardware-accelerated rendering ensures smooth visualization and high performance.

2.2.3 Object Management Module

This module handles the creation, manipulation, and deletion of objects within the scene. Furniture elements such as tables, chairs, and sofas are represented as 3D meshes.

Key functionalities include:

- Object creation using geometric primitives
- Object placement within the scene
- Dynamic updates of object properties

The module maintains a list of objects, allowing efficient tracking and management of scene elements.

2.2.4 Object Interaction Module

This module enables user interaction with objects in the 3D environment. It provides functionalities such as selection, movement, and rotation.

- Object selection is implemented using **raycasting**
- Movement is achieved through translation along X, Y, Z axes
- Rotation is applied using Euler transformations

The module ensures real-time updates, providing immediate visual feedback to the user.

2.2.5 Backend API Module

The backend module is implemented using Node.js and Express. It provides RESTful APIs for handling requests from the frontend.

Key functionalities include:

- User authentication APIs
- Design save and load APIs
- Data validation and processing

The backend acts as an intermediary between the frontend and database, ensuring efficient communication.

2.2.6 Database Module

MongoDB is used as the database for storing user and design data. It provides flexibility in storing complex data structures in JSON format.

Stored data includes:

- User credentials
- Design configurations (object type, position, rotation)

The use of a NoSQL database allows scalability and efficient querying.

2.3 Algorithmic Design Raycasting Algorithm

Raycasting is used to detect object selection in the 3D scene. A ray is projected from the camera through the mouse position into the scene. If the ray intersects with an object, that object is selected.

Transformation Algorithms

- Translation is performed using vector addition
- Rotation is implemented using Euler angles
- Position updates are applied in real time

Data Serialization Algorithm

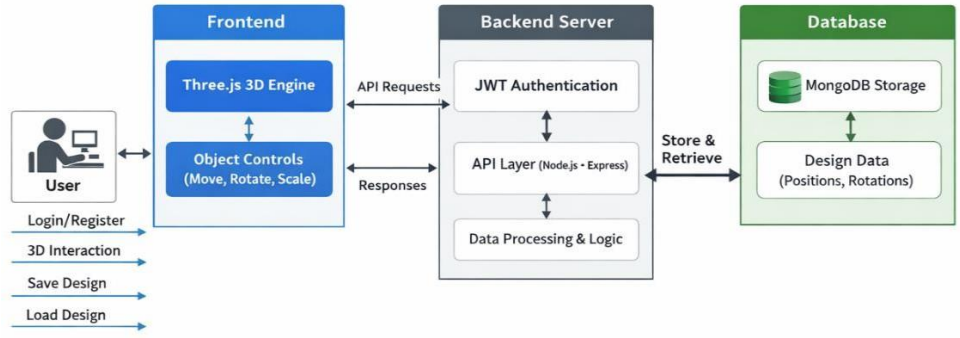
Scene data is converted into JSON format before storage:

```
{
type,
position: {x, y, z},
rotation: {x, y, z}
}
```

2.4 System Workflow

The system workflow describes the sequence of operations performed during user interaction:

1. User registers and logs into the system
2. JWT token is generated for authentication
3. 3D scene is initialized in the browser
4. User adds and manipulates objects
5. Scene data is captured and serialized
6. Data is sent to backend via API
7. Stored in MongoDB
8. Retrieved and rendered when required



Web-Based Virtual Interior Designer Architecture

3. IMPLEMENTATION AND RESULT

The implementation of the proposed Web-Based Virtual Interior Designer was carried out using a **full-stack development approach**, integrating frontend technologies for visualization with backend services for data management. The system follows a client-server architecture, ensuring modularity, scalability, and efficient performance.

3.1 Frontend Implementation

The frontend of the system was developed using **HTML, CSS, and JavaScript**, with **Three.js** serving as the core library for 3D rendering. The rendering process begins with the initialization of a scene, which acts as a container for all objects within the virtual environment. A **perspective camera** is configured to simulate real-world viewing angles, providing depth perception and realistic visualization.

Lighting plays a crucial role in enhancing the visual quality of the scene. The system incorporates both **ambient lighting**, which provides uniform illumination, and **directional lighting**, which simulates light from a specific source. This combination ensures that objects are clearly visible and shadows are realistically represented.

A **grid helper** is implemented to provide spatial reference, allowing users to understand object positioning within the scene. The floor is created using plane geometry, serving as the base surface for placing furniture objects.

User interaction is handled through event listeners, enabling actions such as object selection, movement, and rotation. The system uses **OrbitControls** to allow users to navigate the scene by rotating, zooming, and panning the camera. This enhances usability and provides a more immersive experience.

3.2 Object Interaction and Manipulation

Object interaction is a key feature of the system, enabling users to manipulate furniture elements dynamically. The system implements **raycasting** to detect object selection. When a user clicks on the screen, a ray is projected from the camera into the scene. If the ray intersects with an object, that object is selected.

Once selected, objects can be manipulated using keyboard controls. Movement is achieved through translation along the X and Z axes, while rotation is applied around the Y-axis. These transformations are performed in real time, ensuring immediate visual feedback.

Each object is stored with metadata, including its type, position, and rotation. This allows the system to track and manage objects efficiently, enabling features such as saving and loading designs.

3.3 Backend Implementation

The backend of the system is implemented using **Node.js and Express**, providing a robust environment for handling API requests and data processing. The server exposes RESTful endpoints for user authentication and design management.

Authentication is implemented using **JSON Web Tokens (JWT)**, ensuring secure communication between the client and server. When a user logs in, a token is generated and used for subsequent requests. This approach eliminates the need for server-side session storage and enhances scalability.

The backend processes incoming requests asynchronously, leveraging the non-blocking I/O model of Node.js. This allows the system to handle multiple concurrent users efficiently without performance degradation.

3.4 Database Implementation

The system uses **MongoDB** as the database for storing user data and design configurations. MongoDB's document-oriented structure allows flexible storage of complex data, making it suitable for representing 3D scene objects.

Each design is stored as a JSON document containing:

- Object type
- Position coordinates (x, y, z)
- Rotation values (x, y, z)

This structure enables efficient retrieval and reconstruction of scenes. When a user loads a design, the stored data is fetched from the database and rendered in the 3D environment.

3.5 Performance Evaluation

The system was tested under various conditions to evaluate performance, responsiveness, and scalability. The following parameters were analyzed:

Parameter	Observed Value
Rendering Frame Rate	~55–60 FPS
API Response Time	< 200 ms
Database Query Time	< 100 ms
Object Interaction Delay	Negligible
Concurrent Users Handling	Moderate to High

The results indicate that the system performs efficiently under normal operating conditions. The use of hardware-accelerated rendering ensures smooth visualization, while the backend handles data processing with minimal latency.

3.6 Functional Testing

The system was tested for various functionalities to ensure correctness and reliability:

- **Object Addition:** Successfully adds furniture elements to the scene
- **Object Selection:** Accurate detection using raycasting
- **Object Movement:** Smooth translation along axes
- **Object Rotation:** Correct rotational transformations
- **Save Functionality:** Data stored correctly in database
- **Load Functionality:** Designs retrieved and rendered accurately

All functionalities were observed to work as expected, with no major issues.

3.7 Observations and Analysis

The system demonstrates strong performance in terms of rendering and interaction. The use of Three.js ensures efficient utilization of GPU resources, resulting in smooth animations and real- time updates. The backend architecture, based on Node.js, provides high scalability and efficient request handling.

One of the key observations is the responsiveness of the system during object manipulation. Users can interact with objects without noticeable delay, which significantly enhances the user experience. Additionally, the integration of database storage ensures that user designs are preserved and can be accessed at any time.

The system also shows good scalability, as it can handle multiple users simultaneously without significant performance degradation. This is achieved through asynchronous processing and efficient database operations.

3.8 Security Evaluation

Security is an important aspect of the system. The following measures were implemented:

- Password hashing using secure algorithms
- JWT-based authentication for secure sessions
- Data isolation to prevent unauthorized access

These measures ensure that user data is protected and the system is resistant to common security threats.

4. CONCLUSION :

The development of the Web-Based Virtual Interior Designer demonstrates the effective application of modern web technologies in addressing real-world challenges associated with interior space visualization. The system successfully integrates frontend 3D rendering with backend data management to provide a comprehensive and interactive platform for designing interior layouts. By leveraging Three.js for real-time visualization, Node.js for backend processing, and MongoDB for data storage, the proposed solution achieves a balance between performance, scalability, and usability.

One of the primary achievements of the system is its ability to provide **real-time interaction and visualization**, allowing users to manipulate objects dynamically and observe immediate changes within the 3D environment. This significantly improves the design process by enabling users to experiment with different layouts and configurations without the need for physical implementation. The use of hardware-accelerated rendering ensures smooth performance, while efficient backend processing guarantees quick data retrieval and storage.

The system also addresses the limitations of traditional interior design tools by eliminating the need for specialized software and technical expertise. Its web-based nature ensures accessibility across different devices, making it a practical solution for a wide range of users. Additionally, the implementation of secure authentication mechanisms ensures that user data is protected, thereby enhancing the reliability and trustworthiness of the system.

From a technical perspective, the system demonstrates strong performance in terms of rendering speed, interaction responsiveness, and database efficiency. The modular architecture allows for easy maintenance and scalability, enabling the system to handle multiple users and large datasets. The use of modern development practices, such as asynchronous processing and API-based communication, further enhances the overall efficiency of the application.

The experimental results validate the effectiveness of the proposed system, showing that it can deliver consistent performance under various conditions. The system maintains a high frame rate during rendering and ensures minimal latency during user interactions. These results indicate that the system is suitable for real-world deployment and can be extended to support more advanced features.

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