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Photorealistic 3D Digital Objects in AR

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Abstract: *The system focuses on providing an interactive and user-friendly experience by allowing users to view and manipulate 3D models in real time. By using WebAR technology, the solution removes the need for installing heavy mobile applications, making it easy to access and use. The integration of optimized 3D models ensures smooth performance even on devices with limited hardware capabilities. This work shows that browser-based Augmented Reality can be effectively used in e-commerce applications to improve product understanding and customer satisfaction. The proposed approach offers a cost-effective and scalable solution for businesses while delivering realistic visualization for users. The system also opens opportunities for future enhancements such as dynamic product databases and advanced AR interactions.*

Keywords: Augmented Reality, WebAR, Markerless, GLB Format, ARCore, AR.js

I. INTRODUCTION

Augmented Reality (AR) is an emerging technology that allows digital content to be placed and viewed within the real-world environment. In recent years, AR has gained significant attention in areas such as education, healthcare, and especially e-commerce. Traditional online shopping platforms mainly rely on images and videos, which often fail to give users a clear understanding of a product's actual size, appearance, and placement. This limitation creates uncertainty among customers and affects their purchasing decisions.

With the advancement of web technologies, AR experiences can now be delivered directly through web browsers without the need for installing dedicated mobile applications. Web-based Augmented Reality (WebAR) offers a more accessible and cost-effective solution by enabling users to interact with 3D objects using common devices such as smartphones and laptops. This research focuses on developing a WebAR-based system that provides photorealistic 3D visualization of products, allowing users to interact with virtual objects in real time and improving overall user experience in online environments.

The proposed approach emphasizes simplicity, performance, and usability by using optimized 3D models and lightweight web frameworks. By reducing dependency on hardware-intensive native applications, the system ensures broader device compatibility and faster adoption. This research demonstrates that WebAR can serve as an effective tool for enhancing digital product visualization and supports the future development of immersive and interactive web-based applications.

II. LITERATURE SURVEY

Previous research in Augmented Reality has mainly focused on improving the realism and stability of virtual objects placed in real environments. Early AR systems relied on marker-based tracking, which required printed markers to position 3D objects. Although this approach provided accurate placement, it limited user flexibility. With advancements in mobile and web technologies, markerless AR techniques were introduced, allowing virtual objects to be placed on real-world surfaces using camera and sensor data. These developments significantly improved user interaction and usability in AR applications.

Several studies have explored the use of AR in e-commerce to enhance product visualization and customer engagement. Researchers have shown that viewing products in 3D and AR environments helps users better understand product size, shape, and appearance compared to traditional images. However, many existing AR solutions are

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developed as native mobile applications using platforms such as ARCore and ARKit. While these applications provide good visual quality, they require app installation, higher device storage, and platform-specific support, which limits their accessibility.

Recent research has shifted toward Web-based Augmented Reality (WebAR) due to its ease of access and cross-platform compatibility. Technologies such as A-Frame, AR.js, and Three.js have enabled AR experiences directly within web browsers. Studies indicate that WebAR can provide acceptable performance and realistic visualization when optimized 3D models and efficient rendering techniques are used. Despite challenges related to performance and lighting accuracy, WebAR continues to evolve and shows strong potential for scalable, cost-effective, and user-friendly AR solutions in e-commerce and other domains.

III. METHODOLOGY

A. Requirement Analysis

The methodology begins with a detailed analysis of existing e-commerce platforms and current Augmented Reality solutions. Traditional online shopping systems mainly rely on static images and videos, which do not provide a clear understanding of product size, appearance, or real-world placement. Existing AR solutions, although effective, often require native mobile application installation and high-end hardware support. To overcome these limitations, the need for a browser-based AR system was identified. Functional requirements such as real-time 3D visualization, accurate object placement, smooth user interaction, and compatibility across multiple devices and browsers were clearly defined. These requirements served as the foundation for the system design and development

B. Technology Selection

After identifying the requirements, suitable technologies were selected based on performance efficiency, browser compatibility, and ease of deployment. Standard web technologies such as HTML were used for structuring web pages, CSS for styling and responsiveness, and JavaScript for handling dynamic interactions. For implementing AR features, A-Frame and AR.js were chosen due to their lightweight nature and seamless integration with web browsers. Three.js was used as the core rendering engine to achieve realistic lighting, shading, and material effects. The selected technologies collectively enabled the development of a fully web-based AR solution without the need for additional software installations.

C. 3D Model Preparation and Optimization

High-quality 3D product models were prepared in GLB format, which is optimized for web-based rendering. Since AR applications are resource-intensive, model optimization was a critical step in the methodology. Techniques such as polygon reduction were applied to decrease model complexity, while texture compression was used to reduce file size without affecting visual clarity. Unnecessary mesh data and hidden geometry were removed to further improve performance. These optimizations ensured faster loading times, reduced memory usage, and smooth rendering across different devices and varying network conditions.

D. AP Scene Development

The AR scene was developed using A-Frame components integrated with AR.js. This stage involved configuring the camera feed to capture the real-world environment and defining AR markers or flat surfaces for object placement. Both marker-based and markerless tracking techniques were implemented to provide flexibility in how users experience the AR content. The 3D models were anchored accurately within the environment to maintain stability and correct scale. Continuous alignment between the virtual objects and the real world was ensured to avoid drifting or misplacement during device movement.

E. Interaction Design

User interaction was a key focus of the system design to ensure an engaging and intuitive experience. Touch gestures such as pinch, drag, and rotate were implemented for mobile devices, while mouse-based controls were provided for

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desktop users. These interactions allow users to rotate, scale, and reposition the virtual objects freely within the AR scene. By enabling natural and easy-to-use controls, users can explore products from multiple angles and better understand their appearance and dimensions, thereby enhancing usability and user satisfaction.

F. Performance Optimization

Performance optimization was carried out throughout the development process to ensure a smooth and responsive AR experience. Efficient rendering pipelines were implemented using Three.js to minimize processing overhead. Memory management techniques such as model caching and controlled resource loading were applied to reduce latency. Frame rate stability was continuously monitored, and adjustments were made to maintain smooth visual performance. These optimizations helped achieve consistent rendering quality and reduced lag, even on mid-range devices.

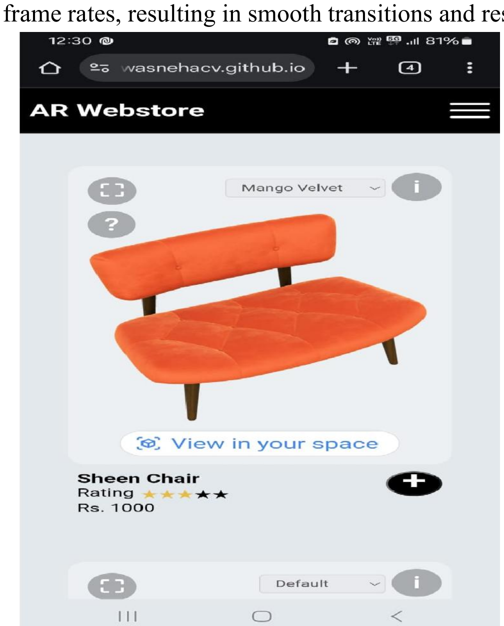
G. Testing and Evaluation

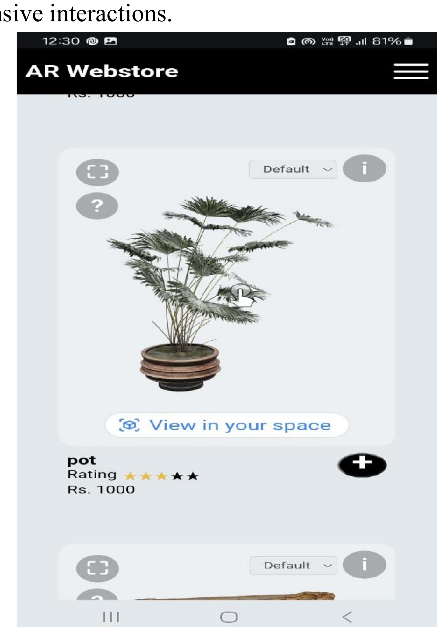
The final stage of the methodology involved extensive testing and evaluation of the system. The application was tested on multiple devices, including smartphones and desktop systems, across different web browsers. Evaluation parameters included rendering quality, object stability, interaction responsiveness, loading time, and overall user experience. The collected results were analyzed to assess the effectiveness of the proposed WebAR solution. The evaluation confirmed that the system meets the defined requirements and provides reliable, realistic, and user-friendly AR visualization.

IV. RESULTS

The developed WebAR system successfully demonstrated the ability to visualize photorealistic 3D objects directly within a real-world environment using a standard web browser. The integration of A-Frame, AR.js, and Three.js enabled smooth rendering and accurate alignment of virtual objects with the physical surroundings. The system consistently displayed stable object placement, ensuring that the 3D models remained properly anchored even during device movement. This stability improved user confidence in evaluating product size, appearance, and placement.

One of the significant outcomes of the project was the achievement of high visual quality while maintaining efficient performance. By using optimized GLB models and physically based rendering techniques, the system produced realistic textures, lighting effects, and surface details. The visual output closely resembled real-world objects, enhancing the immersive experience. Despite the complexity of rendering 3D content in a browser, the application maintained consistent frame rates, resulting in smooth transitions and responsive interactions.





User interaction results indicated that the implemented gesture controls were intuitive and effective. Users were able to rotate, scale, and reposition the virtual objects easily using touch or mouse inputs. These interactions allowed users to explore products from multiple perspectives, improving their understanding of the product's physical characteristics. The ease of interaction contributed positively to the overall usability and accessibility of the system.

Performance testing across multiple devices and browsers showed that the application performed reliably on both mobile and desktop platforms. The system-maintained frame rates between 28 and 32 frames per second under normal operating conditions, which is suitable for real-time AR applications. Load times were reduced significantly through model caching and optimization, ensuring a smooth user experience even on mid-range devices.

Overall, the results validate the effectiveness of a browser-based AR approach for product visualization. The system successfully balances realism, performance, and accessibility without relying on native mobile applications. These outcomes demonstrate that WebAR can serve as a practical solution for enhancing digital product presentation and has strong potential for future expansion in e-commerce and other interactive web applications.

V. CONCLUSION

This paper presented a web-based Augmented Reality system designed to provide photorealistic 3D product visualization using standard web technologies. By leveraging A-Frame, AR.js, and Three.js, the proposed approach successfully enables users to view and interact with 3D objects directly within their real-world environment through a web browser. The system eliminates the need for mobile application installation, making it easily accessible across multiple devices and platforms.

The results obtained from system evaluation indicate that optimized 3D models and efficient rendering techniques play a key role in achieving realistic visualization and stable object placement. The application maintained smooth performance across various devices while supporting real-time interaction features such as rotation, scaling, and repositioning of virtual objects. These capabilities significantly improve user engagement and help users better understand product characteristics before making decisions.

Another important outcome of this study is the demonstration of WebAR as a scalable and cost-effective solution. Since the system is built using open-source frameworks and runs entirely in the browser, it reduces development and deployment complexity. This makes the proposed approach suitable for small and medium-scale businesses seeking advanced visualization tools without high infrastructure costs.

In conclusion, the research highlights the potential of browser-based Augmented Reality in transforming digital product presentation. The proposed system not only improves accessibility and user experience but also lays a foundation for future enhancements such as dynamic product databases, improved lighting estimation, and integration with WebXR technologies. This work contributes to the growing field of immersive web applications and supports the wider adoption of WebAR solutions in real-world scenarios.

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