Development of a Unity Based AR Application of Automotive Chassis Load Distribution

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Abstract. Immersive technologies are the future of learning methodologies in engineering education, particularly in the automobile domain where strong visualization and conceptual understanding is required. In chassis body engineering, students traditionally rely on theoretical formulations, diagrams, two-dimensional images, and online video resources to understand complex topics such as static and dynamic load distribution. This paper represents development of marker less Augmented Reality AR based applications designed to enhance experience in learning automotive chassis engineering. Developed using Unity, the system integrates CAD models imported from standard design software and provides an interactive user interface combining essential theoretical concepts with AR-based visualization. The application utilizes plane detection to detect the surface so as to position the chassis models in a real environment, allowing users to scale, rotate, and examine them from multiple angles. It also includes controls to toggle static and dynamic load conditions, enabling real-time visualization and comparative analysis of load distribution across different chassis configurations. The proposed approach improves spatial understanding and engagement by bridging the gap between theory and visualization. The framework demonstrates the potential of AR in engineering education and can be extended to include stepwise theoretical analysis and visualization of other automotive systems.

1. Introduction

In terms of the rapid development of immersive technologies, especially Augmented Reality, it is expected to revolutionize the engineering education sector. With regard to the specific domain of automotive engineering, it is necessary to understand the structural behavior and interaction of systems. Spatial visualization is one of the essential factors to be understood in the domain. However, with regard to the conventional method of teaching chassis body engineering, it is based on theoretical formulations, two-dimensional diagrams, and pre-recorded visual content. These are found to limit the student's ability to intuitively understand

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complex concepts. The understanding of static and dynamic load distribution is essential in the automotive chassis. These complex concepts are based on multi-directional forces and deformation. These complex concepts are difficult to understand without any practical exposure. AR-based visualization tools are based on the concept of mapping digital models to real-world environments. These tools are useful in understanding complex engineering systems. With regard to the specific objectives of the study, the current study is based on the development of marker-less AR-based application tools for automotive chassis using Unity. The developed application is based on CAD models of different chassis configurations. The developed application is based on an interactive interface that includes theoretical content. The application is based on features such as plane detection to place the models in the real world. The application also includes user controls to scale, rotate, and view objects from multiple angles. Moreover, the application is based on the inclusion of features to toggle static and dynamic loads to view load distribution patterns.

In Immersive technology, Augmented reality (AR) is found to have attracted considerable attention owing to its potential to develop immersive and interactive technologies with minimum hardware and cost requirements. Compared to virtual reality, which requires high-end hardware and computational facilities, the application of augmented reality is found to be more accessible and easier, especially in the domain of engineering education. The application helps in visualizing complex systems in three dimensions, thus creating increased student engagement in the classroom and conceptual clarity among the students. The application is found to be more effective compared to other traditional methods, as augmented reality is found to enhance conceptual clarity, retention, and motivation among the students [1], [4], [8]. The recent reviews on augmented reality application in the domain of engineering education have confirmed the potential of augmented reality in creating an experiential learning environment, where the student can interact with the virtual world in real-time. The application is found to have been effectively utilized in the domain of electronics, robotics, and mechanical system visualization, where the application helps in understanding abstract concepts and ideas through simulations [2], [6], [9]. The application is found to have been effectively utilized in the domain of laboratory-based learning, where the application helps in creating an ideal and safe experimentation environment, especially in the case of infrastructure constraints [4], [11]. In the domain of automotive, the application of augmented reality is found to have been utilized in the domain of maintenance, assembly, and diagnostic applications, where the application is found to have created increased efficiency, reduced human error, and improved user interaction [3]. However, the application is found to have been less utilized in the domain of academic learning, especially in the domain of automotive chassis body engineering. Even though augmented reality application is found to have been effectively utilized in the domain of education and automotive, the application is found to have been less considered in the domain of automobile system visualization, especially in the domain of static and dynamic load distribution in automotive chassis systems. Existing studies largely emphasize general visualization or training applications rather than domain-specific mechanical analysis [1], [3], [7]. This identified gap highlights the need for an AR-based educational framework suitable to the automotive domain, which integrates theoretical understanding with interactive visualization. Interactive virtual simulation and AR technology integration is revolutionizing automotive education and how the auto industry will operate. Research shows that installing an engine such as Unity in a 3-D format will create very realistic training systems on new energy vehicles and reduce costs and risks of safety. In addition, applications running through Vuforia provide users with a method to customize their vehicle; hence, offering an opportunity to provide Virtual Parts Exchange and modifying their vehicles in real-time will allow users to customize their vehicle as if they were still building it out with standard feature specifications.

In conjunction with these applications, there is now a dedicated interior design space for a highly automated vehicle that has created a context-sensitive, three-dimensional interface that can be used as a guide for building out new designs. As a whole, these Application-to-AR systems, with the enhancement of 5G and AI, have yielded a 42% increase in hazard detection and an 18.3% reduction in driver response time; therefore, providing an overall increase in both vehicle performance and safety. The present work addresses this gap by developing a marker less AR application that enables real-time visualization of load distribution on chassis structures, thereby enhancing conceptual understanding and learning effectiveness [16] [17] [18] [19]. The primary objective of this work is to bridge the gap between theoretical learning and practical visualization by leveraging AR technology. The proposed framework aims to improve conceptual understanding, promote active learning, and demonstrate the potential of immersive tools in engineering education. Furthermore, it establishes a foundation for extending AR-based learning systems to include analytical formulations and other automotive subsystems in future developments.

2. Methodology and Application Framework

The methodology for developing the proposed application involves a pipeline of 3D modeling, AR deployment, and interactive visualization. Chassis was sourced, followed by FBX format export, which can be done using the Unity Engine. In Unity, integration of 3D assets with materials, options, and rendering was done. AR environment creation was done using AR Foundation, which allows marker less plane detection for real-world placement of models. For effective and simple handling of application user interface with frame-by-frame information, AR view, and interactive control, it was designed. Load visualization was done using overlays like different color gradients and directional arrow indicators for static and dynamic loading conditions. Finally, user interaction was tested using touch-based manipulation for rotating the model, scaling the model, and getting multiple views to get an complete analysis of the chassis model.

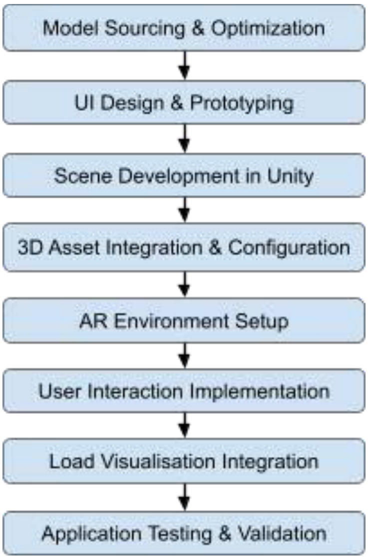

Fig 1. Methodology for Application Development

2.1 Application Framework

The application framework is based on an AR-based educational system with a layer-based application framework, where visualization, interaction, and learning components are incorporated. The marker-less approach of AR technology is selected, where the real-world surface is detected to position and visualize 3D models in an immersive environment. The framework consists of a visualization module for rendering CAD-based models, an interaction module for user interaction, and a learning interface for combining theoretical and practical aspects. The static and dynamic load conditions can be activated using dedicated buttons with on/off features for comparative analysis of load distribution for various chassis configurations. The framework can be utilized for intuitive exploration and can be applied for self-paced learning in various educational environments. Moreover, it can be extended to incorporate real-time simulations, analytical calculations, and integration with other automotive components for overall engineering education.

3. Design and Development of AR Application

The design and development of the proposed AR application was carried out through a structured approach consisting of two major phases: the design phase, which was focused on user interface and experience, and the development phase, which implements functionality and AR-based interaction.

3.1 Design Phase

The design phase began with Sourcing the Models and Optimization, where existing CAD models were refined in Blender to reduce polygon complexity for real-time mobile performance and Textures were Adjusted. This is followed by UI Design and Prototyping in Canva to create layouts and interactive icons. Finally, Scene Development in Unity organizes the application into structured Scenes/modules, including menus and informational pages, ensuring a seamless user transition.

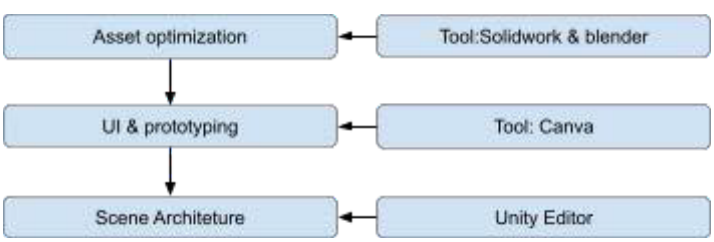

Fig 2. Schematic representation of workflow Design Phase

3.1.1Blender Model Preparation

Blender served as the main tool for polishing and streamlining the 3D chassis data before the models entered the AR application. The team did not build full scenes - they located ready CAD files plus altered them so the Unity Engine could ingest them without strain. Tasks covered material swaps, texture tweaks, scale fixes and polygon cuts until the count stayed low enough for smooth playback on phones but high enough to keep a clear picture. Further small edits straightened stray vertices but also rotated parts so each model sat at the correct angle inside the AR view. Blender exported the cleaned meshes to FBX, a format Unity reads without extra steps. All of those changes lifted on screen clarity and frame rate while the core engineering details of the chassis stayed intact.

Fig 3: Image of Blender model of Ladder chassis.

3.1.2UI Design and Prototyping (Canva)

Initially, the user interface of the application was designed and prototyped using the Canva to get a clear and proper visual idea of the layout. This stage was involved by creating buttons design, icons, background elements, and structuring the content flow of the application. The Canva was used for fast prototyping which allows easy visualization of how users would navigate through different sections like content selection and informational pages. The finalized UI designs where later used as references during its implementations in Unity software, ensuring consistency in visual appearance in visual appearance and improving overall users experience.

Fig. 4: UI Design - Various frames designed in Canva

3.1.3Scene Development in Unity

Scene development was carried out in Unity to organize the application into structured and manageable Scenes. Many scenes were created which includes the main menu, content selection interface, informational pages, and AR visualization scene. Each scene was designed to handle different type of specific functionality, enabling a smooth transition between the different stages of this application. Tools such as Animation and Animator systems, from the Unity animation tools were used to develop Background elements, including static and animated visuals which provides a dynamic and engaging user experience.

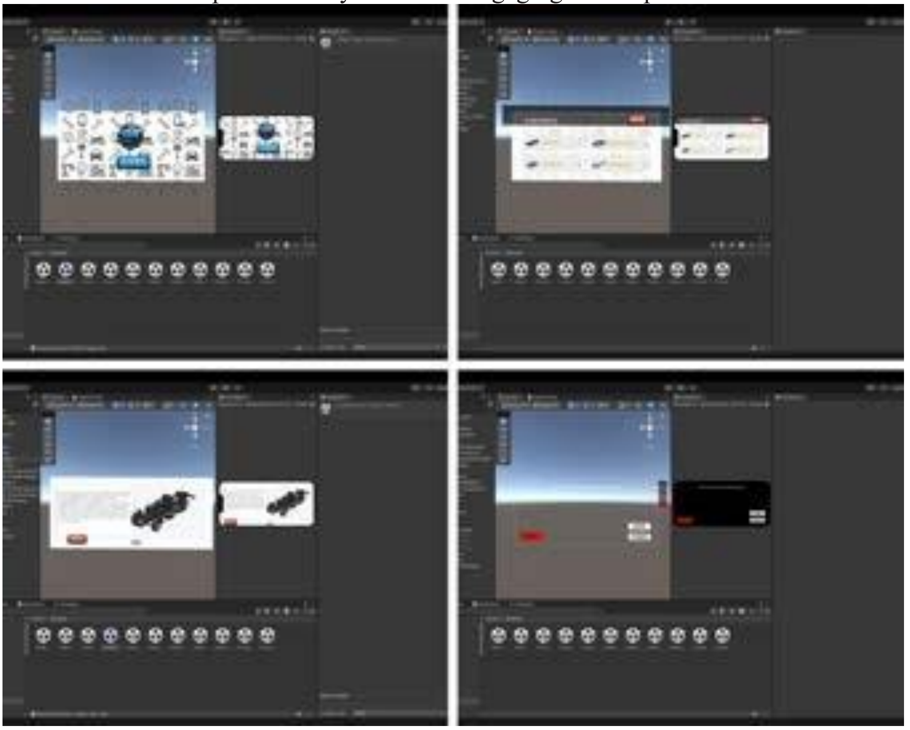

Fig. 5. Scene Development in Unity

3.1.4Development, Application & Validation

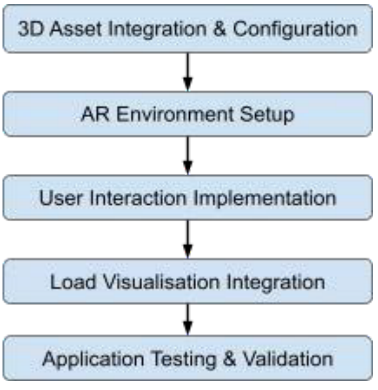

Fig. 6. Schematic representation of workflow Development, Application & Validation

3.1.5 3D Asset Integration and Configuration

The 3D chassis models were imported into Unity software in FBX format and was introduced into the application environment. During the stage materials, textures, and rendering properties were configured in order to ensure the realistic visualization along with the maintaining the performance efficiency. Proper positioning of the models were also ensured to achieved to get an accurate representation within the AR environment.

3.1.6 AR Environment Setup (AR Foundation + ARCore)

The AR environment was established using AR Foundation in Unity using the AR Core which provides support for marker-less tracking on Android devices. This setup enabled the application to detect real-world surfaces through plane detection and create a stable environment for placing virtual objects (chassis of the vehicle). The AR session and origin were configured to ensure accurate tracking and alignment between virtual models and the physical world. This stage forms the foundation of the AR functionality, allowing smooth and easy to use integration of digital content into real-world surroundings.

Fig. 7. AR Environment Setup in Mobile Interface.

3.1.7 User Interaction Implementation (Touch & Gestures)

User interaction was implemented using touch-based input and gesture recognition to enable proper manipulation and handling of the 3D models. C# scripting within the Unity was used to develop the functionalities such as tapping for model placement, pinch gestures for scaling, and drag gesture for rotation. Interaction scripts were designed to ensure smooth and responsible control, allowing users to inspect the chassis model from different angles. This enhances spatial understanding and provides a hand-on-experience.

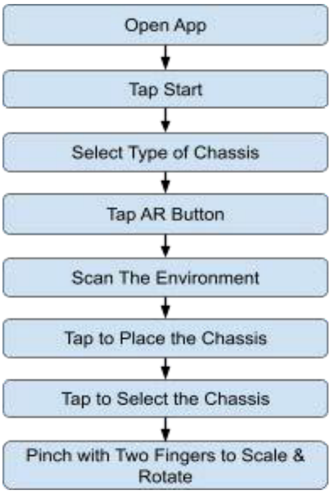

Fig. 8. User Interaction Implementation (Touch & Gestures)

3.1.8. Load Visualization Integration

Load visualization features were later added to represent the static load distribution on the chassis models. This was achieved by using visual indicators such as color gradients and directional arrows, which helps the users to understand that how loads are distributed across different parts of the chassis structure. Interactive buttons were implemented to enable users to toggle these visualization modes, allowing comparative analysis and improving conceptual clarity. This feature plays a key role in bridging theoretical concepts with visual representation.

Fig. 9. Load visualization from Mobile Perspective.

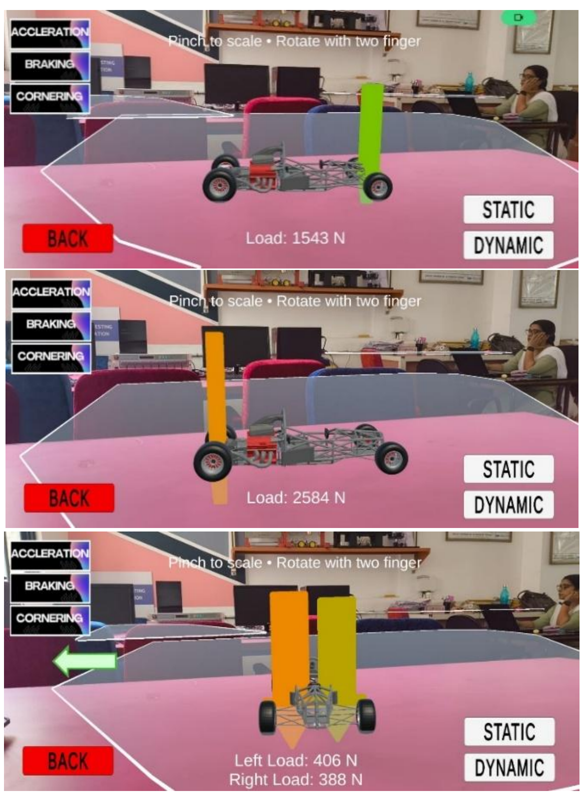

Fig. 10. Load visualization from Mobile Perspective

The dynamic forces operating on the chassis models were represented by an update to the system's load visualization features. By synchronizing the model with the motion of a connected phone, this dynamic representation monitors how the load changes from its initial baseline state. The program determines real-time changes in load intensity and distribution throughout the structure when the user moves or tilts the phone. Colour gradients on the model alter in real time to show areas of rising or falling stress, moving through a spectrum. Additionally, the directional arrows change in length and size, becoming shorter when the load decreases and larger to indicate greater force magnitudes. Interactive buttons allow users to toggle between these modes, providing a direct visual bridge between the physical motion of the phone and theoretical load concepts.

3.9 Application Testing and Validation

The final stage was the testing and validation of the application, ensuring properly that the application is functioning well and is user-friendly, which will lead to make the app ease to use. The application was tested using the different models of Android platforms to ensure accurate plane detection, appropriate model placement, and ease of interaction through scaling and rotation. The challenges came across us was, such as incorrect model placement and interaction, were addressed and solved by making appropriate changes to the scripts and the AR configuration. The feedback from the users was also taken into consideration to make sure the ease of use and the effectiveness of the learning. The testing phase confirmed the application's reliability and interaction, making it appropriate for educational purposes.

4. Testing of AR Application

The developed and updated AR application was addressed to systematic testing to assess the application's functionality, performance, and usability on mobile devices running Android and supporting the AR-Core platform. The testing was conducted under real-world conditions to ensure the application's reliability of use in the marker-less augmented reality system and the application's interaction and visualization features' effectiveness.

4.1 Functional Testing

Functional testing was performed to ensure that all the features of the application are functioning as per required, including the detection of a plane, correct placement of a model, interaction, and visualization of the load. Initially, the application was found to experience some number of issues, including the improper placement of the chassis model, difficulties experienced while scaling and rotating the chassis model, and improper placement related to the detection of the plane. The problems which were experienced while testing the application were attributed to inaccuracies in the detection of a plane and interaction. To improve the application, changes were made to the AR interaction scripts and object anchoring, ensuring that the object is properly positioned on the detected plane. The application was also improved to ensure that the touch input is handled smoothly and easily, facilitating the scaling and rotating of the object. After improving the application, all the application functionalities worked as required.

4.2 Performance Testing

Testing of the performance was carried out to evaluate the responsiveness and stability of the application during real-time operations by the users. The application demonstrated and showed the smooth performance on different models of Android smartphones, with stability of 3D models and minimal latency during interaction. Optimization techniques such as reducing polygon count of chassis models and efficient assets management contributed to maintaining consistent frame rates and preventing performance drops. The AR experience remained responsive during continuous usage, including model manipulation and visualization of load conditions.

4.3 Usability Testing

Testing of usability was performed by allowing multiple users to use the application, including students, to interact with the application and provide feedback on how its ease of use and learning effectiveness. The results showed that the application is intuitive and user-friendly which is easy to use, with a clear interface and simple navigation flow. Users were able to easily select chassis types, access informational content, and transition into AR mode without any difficulty. Feedback from users suggested that the application is effective in helping understand the basic concepts of automotive chassis and load distribution through interactive visualization anywhere and anytime. It was also observed that the application has strong potential to be expanded into a comprehensive learning platform by incorporating additional topics from the syllabus of engineering. Overall, the testing results confirm that the application successfully delivers an engaging and educational AR experience.

5. Conclusion

In conclusion, AR has made substantial contributions to the dissemination of automotive engineering knowledge. First, Through the marker-less immersive environment provided by AR, students can repeatedly observe complex chassis configurations and loadings which are difficult to visualize, allowing them to quickly establish a mental model. Second, using this AR application, students can learn knowledge on their own outside of the classroom without being restricted by laboratory hardware through creative educational methods, transcending the limitation of flat drawings. Moreover, immersive technologies can reduce educational expenses, lower the need for expensive physical models and training facilities, and allow for maximal resource use. Augmented Reality (AR) Technology Opportunities: Blending with Other Modern Teaching Methods. Future work should focus on blending the developed AR system with other modern teaching technologies. These technologies include artificial intelligence (AI), such as large language models (LLMs), real-time simulations, and step-by-step formulas. By integrating these technologies into AR experiences, automotive graphics could potentially be more interactive, customized and provide real-time solutions. Additionally, exploring the impacts of immersion technology on various automotive sub-systems and promoting cross-collaborative teaching methods will help lead to new efficient and flexible technology. These technologies could help establish AR as a powerful tool for structural analysis and change the future path of engineering education.

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