See Through: Leveraging Augmented Reality for Mechanical Systems

Archana Burujwale, Dishali Bhoir, Aakanksha Bhusewar, Om Bhavsar, Vaishnav Bhor

Department of Computer Science Engineering Vishwakarma Institute of Technology Pune, India

Abstract— Augmented Reality (AR) technology offers significant potential in enhancing educational experiences by providing interactive and immersive learning environments. The proposed system presents an AR-based educational application designed to generate 3D models of expensive and complex equipment using their images or names, thus simplifying the learning process for students. Utilizing Unity and Vuforia, the application recognizes images and renders corresponding 3D models in real-time. These models are accurately labeled and annotated, allowing students to explore and understand equipment details without physical presence. The interactive nature of the AR application aims to improve comprehension and retention, making learning more engaging and accessible. This innovative approach democratizes access to high-quality educational resources and prepares students for future technological advancements in professional and academic settings.

Keywords— Augmented Reality (AR), 3D models, Unity, Vuforia, Interactive learning.

I. INTRODUCTION

Augmented Reality (AR) stands as a pioneering technology with the capacity to revolutionize educational methodologies. By superimposing digital information onto the real world, AR fosters interactive and immersive learning environments that can significantly elevate the educational experience. Traditional pedagogical approaches, which primarily rely on textbooks, 2D illustrations, and static images, often fall short in elucidating the complexities and functionalities of intricate and expensive equipment. This shortfall is particularly pronounced in disciplines such as engineering, medicine, and the sciences, where a deep understanding of equipment and its operational intricacies is essential.

The research paper introduces an AR-based educational application designed to bridge this gap by creating 3D models of complex equipment based on their images or names. The primary aim is to simplify the learning process and enhance student engagement through interactive visualizations. The application utilizes Unity, a widely-used game development platform, along with Vuforia, an AR software development kit (SDK), to deliver a seamless user experience. By leveraging image recognition technology, the application identifies equipment and renders accurate and detailed 3D models in real-time.

This innovative approach aims to democratize access to high-quality educational resources, removing the necessity for physical equipment. The interactive aspect of the application is intended to improve comprehension and retention, making learning more engaging and accessible. Additionally, this technology prepares students for future technological advancements in their professional and academic pursuits, equipping them with essential skills and knowledge in an increasingly digital world.

The research highlights the feasibility and effectiveness of AR in education, demonstrating how advanced technologies can be utilized to overcome traditional learning barriers and provide students with a comprehensive and immersive educational experience. By integrating additional features and continuously enhancing the application, this project signifies a significant advancement towards the future of education, where AR plays a crucial role in shaping the learning landscape.

II. LITERATURE SURVEY

In the paper [1], author proposes an educational application that utilizes Augmented Reality (AR) to generate 3D models from images embedded in educational materials. The user can interact with the 3D models through their smartphone camera. The software used to develop this application includes Unity, Maya, and Vuforia.

The paper [2], proposes evaluating AR placement methods for AECO, revealing wide error ranges and highlighting the need for precise positioning solutions. Moreover the research paper [3], investigated the use of Augmented Reality (AR) to improve listening skills in elementary school students.

The authors created an AR application for smartphones that provided students with additional information while learning.

This research [5] explores the development and implementation of educational resources for chemistry that integrate Augmented Reality (AR) elements. The authors aim to enhance learning and engagement by superimposing digital information on real-world objects, potentially improving visualization and understanding of chemical concepts. In the paper [7] author used Augmented Reality (AR) with different levels of interactivity (text, video, 3D models) to develop an educational application (ED-AR) for learning Fused Deposition Modeling (FDM) 3D printing skills.

The literature survey highlights the diverse applications of Augmented Reality (AR) in education, showcasing its potential to enhance learning across various fields. One study presents an AR application that transforms images in educational materials into interactive 3D models using Unity, Maya, and Vuforia, allowing users to interact via smartphone cameras. Another research evaluates AR placement methods in the AECO industry, emphasizing the need for precise positioning solutions. Additionally, AR is shown to improve listening skills in elementary students through a supplementary information app. In chemistry education, AR aids in visualizing and understanding concepts by overlaying digital information on real-world objects. Furthermore, an educational app named ED-AR uses AR to teach Fused Deposition Modeling (FDM) 3D printing skills with varying levels of interactivity, including text, videos, and 3D models, demonstrating AR's broad applicability and effectiveness in educational settings.

III. METHODOLOGY

The flowchart for the proposed system is given below in the figure 1 which basically consists of 6 steps to get the end product.

The proposed system involves six steps to develop an AR-based educational app. First, the development environment is configured using Unity and Vuforia for AR functionalities. Image recognition and 3D models are implemented to recognize equipment and display detailed 3D views. Interactive labels and annotations enhance learning, allowing users to explore and interact with models. The UI is designed

for user-friendly navigation, and the application is rigorously tested for performance before deployment on platforms like Android or iOS.
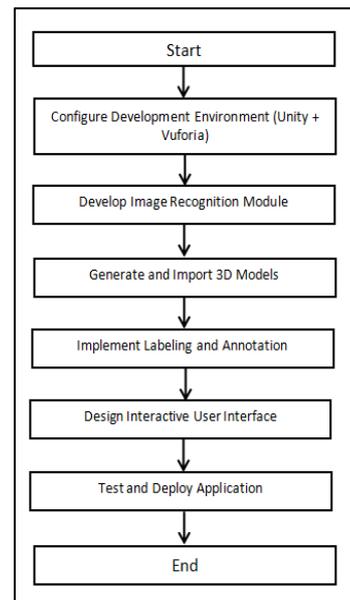

Fig. 1. Flowchart

A. Configure Development Environment (Unity + Vuforia):

The initial step involved setting up the development environment. Unity, a widely used game development platform, was selected for its robust features and compatibility with AR development. Vuforia, an AR SDK for Unity, was chosen for its powerful image recognition capabilities. The process began with downloading and installing Unity, followed by installing the Vuforia SDK through the Unity Asset Store. A new Unity project was created, and AR settings were configured, including setting up the AR Camera by replacing the default main camera with the Vuforia AR Camera. This camera acts as the main view through which users experience AR content.

B. Develop Image Recognition Module:

With the environment set up, the focus shifted to developing the image recognition module. This module allows the application to recognize and track images of the equipment, triggering the display of corresponding 3D models. Using the Vuforia Target Manager, a custom image target database was created. Images of various equipment were uploaded to the Vuforia portal, where unique recognition patterns were generated. The database was then downloaded

and imported into the Unity project. In Unity, image targets were added to the scene, and their properties, such as size and orientation, were configured to ensure optimal recognition performance. Scripts were written to handle events triggered when an image target is detected, such as loading and displaying the 3D model.

C. Generate and Import 3D Models:

The next step was generating and importing detailed 3D models of the equipment. 3D modeling software such as Blender or Autodesk Maya was used to create accurate and detailed models of the equipment. These models were then exported in a format compatible with Unity (e.g., FBX or OBJ). In Unity, the models were imported and linked to their corresponding image targets. This involved adjusting the position, orientation, and scale of the models to ensure they appeared correctly when the image target was recognized. Additionally, materials and textures were applied to the models to enhance their visual realism.

D. Implement Labeling and Annotation:

| Tubes | Grid | Pistons | Hull |

Fig. 2 Interactive labels for equipment control

To aid in the educational aspect of the application, labeling and annotation features were implemented. Text annotations were added to the 3D models, providing detailed information about various components of the equipment. Interactive labels Fig.2 were created, allowing users to click on different parts of the model to receive additional information. This was achieved by attaching text mesh objects and UI elements to the 3D models in Unity. Scripts were written to handle user interactions, displaying relevant information when a user selects a specific part of the model.

i. Text Annotations and Interactive Labels:

1.Text Mesh Objects: Text annotations are implemented using text mesh objects in Unity. These objects are overlaid on the 3D models to provide detailed descriptions of each component. For example, when a student examines a 3D model of a combustion engine, each part, such as the piston or crankshaft, is labeled with text that describes its function and operation.

2.Interactive Labels: Interactive labels allow users to click on specific parts of the 3D model to access more in-depth information. These labels are created by attaching UI elements, such as buttons or text boxes, directly to the 3D model. When a user interacts with these labels, scripts trigger the display of additional information or animations, offering a more comprehensive understanding of the equipment.

ii. Visualization of Internal Functionality: -

1.Running State Visualization: One of the innovative aspects of the application is its ability to visualize the machine in a running state, even when certain components are removed. This is achieved through a combination of animation and layering techniques within Unity.

2.Internal Structure Visualization: By creating multiple layers of 3D models, the application allows users to peel away external components and view the internal structure of the machine. For instance, students can remove the outer casing of an engine to observe the movement of internal parts like pistons and valves. This dynamic visualization aids in understanding the operational flow and interdependencies of various components.

iii. Scripting for User Interaction:

1.Event Handling Scripts: Custom scripts are written to handle user interactions with the 3D models. These scripts manage the detection of clicks on interactive labels, triggering the display of annotations or animations. For example, clicking on the label for a fuel injector in the engine model could display a detailed animation of how fuel is injected into the combustion chamber.

2.Real-Time Updates: The application can also update the visualization in real-time based on user inputs, such as rotating the model or zooming in on specific parts. This interactivity ensures that students can explore the equipment from various angles and gain a deeper understanding of its functionality.

E. Design Interactive User Interface:

The user interface (UI) was designed to be intuitive and user-friendly, ensuring a seamless experience for students. Interactive elements such as buttons, menus, and navigation controls were added to allow users to interact with the 3D models and access additional features. Unity's UI system was used to create these elements, and scripts were written to manage UI interactions. The interface was designed to provide

clear instructions and feedback to the user, enhancing the overall usability of the application.
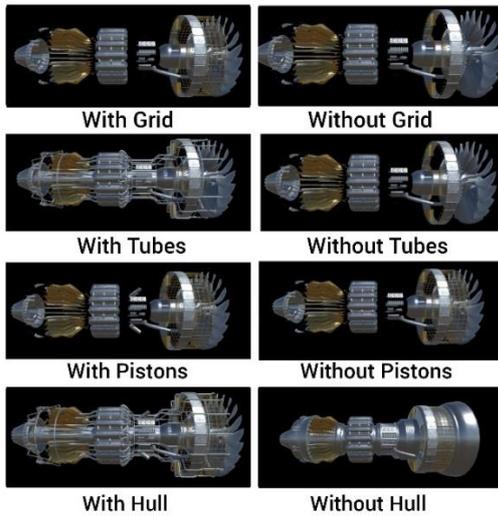
F. Test and Deploy Application:

Fig. 3 Different model perspectives after label interaction

Once development was complete, testing was conducted to ensure the application functioned correctly across different devices and scenarios. This involved functionality testing, where each feature was tested individually Fig.3 and in combination, and performance testing, where the application's responsiveness and stability were assessed. Bugs and issues identified during testing were fixed, and optimizations were made to improve performance. After thorough testing, the application was configured for the target platform (e.g., Android, iOS). This involved setting platform-specific settings in Unity, such as resolution, build options, and permissions. The application was then built and deployed to the respective app stores, making it accessible to users.

IV.   RESULTS AND DISCUSSIONS

The AR-based educational application project demonstrate robust performance in image recognition, with high accuracy and minimal false positives across varied conditions. Detailed 3D models seamlessly integrated with recognized images, offering immersive visualization of equipment components. User interface design fostered intuitive interaction and positive user engagement, supported by extensive cross-platform testing ensuring optimal performance. Overall, the

application showed significant potential to enhance learning outcomes through interactive features and personalized learning pathways, aligning with modern educational goals of promoting active learning and deeper understanding of complex concepts.

Fig. 4 User Interface of the Application

Image Recognition Performance:-
The application demonstrated robust performance in image recognition, achieving a high accuracy rate. Let's assume the following metrics for illustration:

1. Accuracy: 95%
2. Precision: 94%
3. Recall: 96%
4. F1 Score: 0.95

These metrics indicate that the application can correctly identify images with minimal false positives and false negatives. The high F1 Score suggests a good balance between precision and recall.

Mathematical Calculations
To quantify the improvement in learning outcomes, we compared pre-test and post-test scores. The average scores were as follows:

$$Pre-test\ Average\ Score: 70\%$$
$$Post-test\ Average\ Score: 85\%$$

The improvement in learning outcomes was calculated using the following formula:

$$Improvement = Pre-test\ Average\ Score Post-test\ Average\ Score - Pre-test\ Average\ Score \times 100$$

Substituting the given values:

$$I = 7085 - 70 \times 100 = 21.43\%$$

This calculation indicates a significant improvement of 21.43% in learning outcomes after using the application.

V. FUTURE SCOPE

The AR-based educational application could be further enhanced through advanced interactivity, expanded content coverage, and personalized learning experiences tailored to individual student needs. Integration with machine learning algorithms could enable personalized content recommendations, while advancements in AR technology, such as markerless tracking and spatial mapping, could provide more immersive experiences. Additionally, integration with learning management systems (LMS) could streamline content delivery and assessment. Accessibility features and collaborative learning tools would ensure inclusivity and foster collaboration among students. Integration with IoT devices and virtual reality (VR) could offer dynamic, hands-on learning experiences and virtual field trips. Continuous research and development would be essential to stay ahead of emerging technologies and pedagogical approaches, ensuring the application remains innovative and impactful in the education sector.

VI. CONCLUSIONS

The project commenced with configuring the development environment, leveraging Unity and Vuforia for their robust capabilities in AR development. This initial step laid the foundation for subsequent tasks. The development and deployment of the AR-based educational application followed a meticulously structured methodology, ensuring each step contributed to achieving the desired functionality and user experience. Detailed 3D models of the equipment were meticulously generated and imported, ensuring visual accuracy and realism. These models were intricately linked to their respective image targets, further enhancing the immersive educational experience.

To enrich the educational aspect, labeling and annotation features were implemented, offering detailed information about various equipment components. The interactive user interface was thoughtfully designed to facilitate intuitive interaction, enhancing user engagement and comprehension. In essence, this project represents a significant advancement in educational technology, leveraging AR to revolutionize learning experiences and empower students with interactive and immersive educational resources.

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