An Interactive Augmented Reality System for Earth Exploration Using Geospatial Mapping and Multimedia Integration

Hemanth B G[1], Dr. Kavitha Sooda HOD[2], Sri Raksha S[3], Hemalatha M[4], Mr. Shreevatsa D S[5]
[1,2,3,4]*Department of CSE BMSCE, Bengaluru, India*
[5]*Assistant Professor, Department of CSE BMSCE, Bengaluru, India*

***Abstract*—The use of Augmented Reality (AR) has proven itself to be an effective technology for improving the interaction between users through the integration of virtual elements into the real world. In this paper, an Interactive Augmented Reality Earth Exploration System is proposed to create an engaging and educational platform for studying the geographical and cultural data. It is implemented in Unity using AR Foundation and XR Interaction Toolkit to show a 3D model of the Earth sphere in augmented space on smartphones. Countries are located on the Earth sphere based on their latitude and longitude coordinates, and users can select any country to get multimedia information like the country's flag, national animal, national bird, and corresponding audio information. Scriptable Objects are used to manage metadata efficiently. This research reimagines the process of studying geography into a highly interactive and intuitive one by leveraging AR visualizations and touch interaction.**

***Index Terms*—Augmented Reality, Unity, AR Foundation, XR Interaction Toolkit, 3D Earth Visualization, Geospatial Mapping, Interactive Learning, Educational Technology and Multimedia Information System, Mobile AR.**

I. INTRODUCTION

In turn, AR proves to be one of those technologies that enhance the interaction process, combining virtual objects and the physical world around people. The development and implementation of advanced mobile computing technology, along with modern AR platforms, allows AR application usage to become even easier compared to previous years. There are numerous areas where augmented reality finds its place, such as educational sphere, gaming, medicine, navigation, entertainment, and many other spheres.

In general, there is a great potential associated with AR applications that can be used for educational purposes since they are capable of presenting the data in a more engaging way. Traditional methods of teaching students, especially in such areas as geography and world studies, depend a lot on books and maps, which sometimes cannot ensure a better level of understanding and exploration of the material. On the contrary, augmented reality provides students with an opportunity to get an insight about new things through visualization.

Using AR visualization to study countries, cultures, and geographical entities provides certain benefits in terms of studying them properly. An AR-based platform that includes the model of the Earth and allows the interaction with it helps people explore different countries and obtain information on the spot. Some Augmented Reality platforms prove their efficiency when applied in navigation, interactive visualization and object-oriented learning areas [6], [8], [11].

The latest Augmented Reality technology advancements have made it possible to build interactive systems which possess both stable performance and high responsiveness. The development of mobile AR applications has reached new levels because markerless tracking, plane detection, real-time object placement, and virtual object alignment techniques improve their realistic appearance and user-friendliness [2], [3], [9], [10], [13]. The new technology base enables developers to create educational AR applications which merge the spatial interactions with multimedia content in order to build their applications.

The authors developed the Interactive Augmented Reality Earth Exploration System to create an educational tool which uses 3D Earth models in augmented reality to teach students about different countries. The research team developed a new system which enables users to explore virtual countries through their latitude and longitude coordinates on a virtual globe. The system shows users multimedia content about their selected country. This includes the national flag together with its representative animal and bird species. The developers built the system through Unity together with AR Foundation and XR Interaction Toolkit, which enables users to interact with the system through their mobile devices.
As a result, the most crucial purpose of this particular research is to integrate traditional approaches to teaching students about geography through digital means, making use of the more visual exploration of countries. With all the integration of geospatial mapping, multimedia data, and AR interactivity in one single system, one can assume that a higher level of engagement may be attained through the process. In turn, this paper proceeds with literature review and methodology sections, as well as a system implementation and findings.

II. LITERATURE SURVEY

Poudel and Poudyal [1] proposed a CNN-based approach using transfer learning for classification of waste materials. Their work demonstrates how DL models can be effectively adapted for real-world classification tasks, improving accuracy while reducing training time.
Łysakowski et al. [2] developed a real-time onboard object detection system for augmented reality using YOLOv8. Their approach enhances head-mounted displays by enabling fast and accurate detection, significantly improving AR interaction experiences.
Kim et al. [3] explored the use of augmented reality in urban planning for data visualization. Their study highlights the challenges and opportunities in integrating AR systems for better spatial understanding and decision-making.
Laidoudi et al. [4] introduced a hybrid CNN-transformer based approach for real-time indoor object detection. Their model combines the strengths of convolutional and transformer architectures to improve detection accuracy in complex indoor environments.
Gururaj et al. [5] presented an augmented reality-based object detection system using the Flying Dino framework. Their work focuses on enhancing user interaction with virtual objects through real-time detection in AR environments.
Sahu et al. [6] proposed an edge-assisted energy optimization technique for mobile AR applications. Their research improves battery efficiency and computational performance, making AR applications more practical for mobile devices.
Gavgiotaki et al. [7] provided a comprehensive review of gesture-based interaction techniques in AR systems. Their study emphasizes the importance of intuitive user interaction mechanisms for enhancing user experience.
Maneli and Isafiade [8] conducted a comparative evaluation of augmented reality frameworks focusing on plane mapping and resource utilization. Their findings help in selecting efficient AR frameworks based on performance metrics.
Lu and Yihao [9] designed an interactive augmented reality application for mobile platforms. Their work demonstrates how AR can be effectively implemented on mobile devices to enhance user engagement.
Ganesh Sundaram et al. [10] proposed a plane detection-based AR system for product trial applications. Their system enables users to visualize products in real-world environments, improving decision-making in e-commerce.
You et al. [11] presented an approach for real object detection in augmented reality systems. Their work improves detection accuracy and contributes to more seamless integration of virtual and real-world objects.
Rokesh Maran et al. [12] developed an indoor navigation system using augmented reality and the Unity engine. Their approach enhances navigation in indoor environments through real-time AR guidance.
Daling and Schlittmeier [13] conducted a scoping review on Augmented Reality, VR, and MR-based training systems. Their study evaluates performance outcomes and highlights the effectiveness of immersive technologies in training scenarios. Du et al. [14] proposed a rapid oriented detection method for virtual components in augmented assembly systems. Their approach improves precision and efficiency in industrial AR applications.
You et al. [15] discussed recent advancements in augmented reality-based object detection systems.

Their work provides insights into evolving techniques and future directions in AR integrated detection models.

In this study, an Interactive AR Earth Exploration System is presented as a combination of AR, geospatial mapping, and interactive educational systems for the provision of engaging experience. While conventional approaches to geographical education relied heavily on textbooks and other non-digital materials, the system represents an advanced solution for exploring a virtual 3D model of Earth in real-life settings. In terms of functionality, the system includes Augmented Reality environment initialization, placement of the Earth model, country localization based on lat-long coordinates, selection of objects using gestures, multimedia content loading, and real time rendering of the scenes.

1. AR Environment Initialization and Controlled Scene Setup: The first step in creating an interactive AR environment involves initiating an AR session using AR Foundation in Unity3D. The mobile camera constantly analyzes the physical environment for identification of a suitable surface for placing objects (tables, floors, and other open spaces). As a result of this stage, a controlled environment is created that allows for detecting a proper place to place the virtual Earth visualization model before the actual placement is performed. This process is not applicable to static 3D solutions since AR provides an opportunity to add objects in real-life environments.
2. Plane Detection and Virtual Earth Placement: With the commencement of the augmented reality (AR) session, the system engages in real-time plane detection to determine any surface which could be used as the basis for placing the virtual Earth model. When a suitable plane is identified, users can use touch interactions to place the globe of Earth on the screen of the device. With a chosen location, the system creates an instantiation of the three-dimensional Earth model on the identified surface, ensuring stability in the positioning of the virtual object in the physical world.
3. Country Positioning Using Latitude and Longitudinal Mapping: In this framework, geospatial mapping is utilized to position individual countries accurately within the modelled globe. Countries are assigned a set of geographical coordinates indicating their positions on the globe in terms of latitudes and longitudes. Through this procedure, spatial relations among regions and countries are maintained and the educationally relevant aspect of the application is improved through the creation of coordinate-based maps.
4. Interactive Country Selection and Input Handling: As a means of enhancing interaction and promoting an exploratory process, the system makes it possible for users to engage actively in selecting a particular country from the Earth model. By using touch interactions, users can choose one country at a time by tapping the marker or relevant interactive elements on the screen of the device. The chosen country triggers information provision within the application and thus transit the application from a visualization tool into an educational tool.
5. Multimedia Display and User Interface Integration: After selection, the chosen country triggers the display of a series of multimedia-based information panels. The panel contains country names and flags, national animals and birds, together with relevant video or audio elements. This is presented through a responsive interface provided by the AR application. The use of multimedia-based information panels makes the application more educational than traditional approaches to geographical studies.
6. Country Data Management and Content Handling: In order to provide scalability and facilitate efficient content management, the suggested system employs the concept of Scriptable Objects in Unity which will store the data about each country used in the game. The latter is associated with metadata, comprising textual, image and media information. The modular approach ensures that it is possible to update or add the countries and their data without influencing the codebase of the application.
7. Real-Time Rendering and Interactive User Experience Enhancement: Visual improvements will include optimization and fast loading of graphics elements, including Earth, its countries and information panels, as well as providing smooth UI transitions. The proposed system

relies on the following components of the workflow process: AR plane detection, placing the Earth object, matching countries to the geospatial map, interactions with the world and the Earth, and multimedia information rendering. It is these processes that distinguish the proposed solution from typical educational games because they create an immersive user experience while exploring the Earth.

III. APPLICATIONS

Interactive Augmented Reality Earth Exploration System proves practical applicability for educational and interactive applications. Unlike typical geography classes that involve books, maps, and other static means, this solution combines visualization, country exploration, and multimedia learning. Thus, it can be used for the following:

1) Academic Learning - Educational institutions such as schools and colleges can introduce this system to create a highly interactive and engaging medium for studying geography,and other related topics. Incorporation of AR

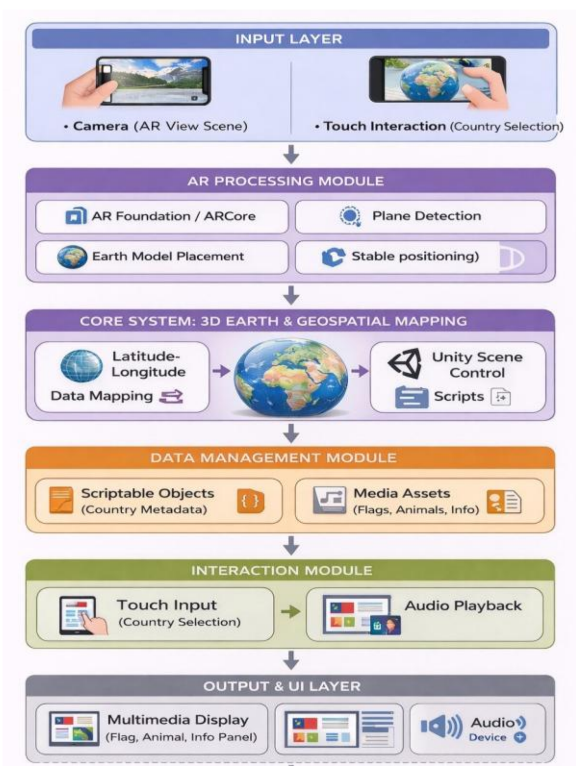

Fig. 1: System architecture of the proposed AR Earth Explorer framework.

The architecture involves an organized and hierarchical structure of the AR Earth Explorer game development process, including handling user inputs, AR environment detection, managing objects in the scene, metadata management, interaction control, UI generation, and final output.will improve the level of immersion and help understand concepts better.

2) Interactive Geography Exploration - This application lets the user get a chance to explore their geography independently as one gets to interact with the virtual world map as well as get the information about the selected country.

3) Museum and Exhibition Installations - Museums, and science centers, educational exhibits can adopt this framework, allowing visitors to interact with the AR globe to learn about different countries, symbols, and cultures.

4) Children's Learning Applications - It can also be applied for children's educational systems by offering a highly entertaining and visually appealing way of learning. Interactive aspect of the application should increase curiosity and motivation of young users.

5) Research and Human–Computer Interaction Studies - Finally, this framework can serve as a prototype for studying AR-based educational interfaces. Researchers can use it to study user interaction and effectiveness of immersive environments.

IV. RESULTS AND PERFORMANCE EVALUATION

A. Overall Results

AR Earth Explorer implementation was executed using Unity 6.1, AR Foundation, and XR Interaction Toolkit. An ability to generate a steady 3D globe in an augmented space and correct placement of interactive country cubes based on their latitude and longitude values was achieved successfully. The Augmented Reality environment detected the horizontal surfaces accurately and anchored the globe properly, therefore, it provided a natural way of interacting with the Earth. The application provided an opportunity to interact with the application using the touch-based technique in order to select country cubes and retrieve relevant multimedia data from the dynamically created user interface panel. Specifically, the user was provided with educational information regarding selected countries in terms of their flags, national animals, birds, and additional media. The media components worked efficiently without any lags, which in turn contributed to the general user experience. In addition to the functionality of the system, responsive behavior on mobile platform was observed. Specifically, the use of Scriptable Objects and lazy loading for multimedia made the application work efficiently and effectively. Overall, proposed system accomplished its purpose successfully and provided an immersive educational experience to the users.

B. Functional Validation

The AR Earth Explorer software program was validated in terms of functionality by running the different modules of the pipeline interaction process. It was confirmed that the application is capable of initiating the Augmented Reality session and identifying appropriate horizontal planes where the virtual Earth model can be positioned. After identifying an appropriate surface, the model was successfully created and anchored in the physical world. All country cubes created on the Earth model were placed in their appropriate geographical positions based on the latitude-longitude map. The user was able to select any country using touch-based interaction, which was accurately detected by the system without encountering errors. As a result, the corresponding information panel for the chosen country was opened, displaying relevant educational information such as the flag, national animal, and national bird of that particular country. Furthermore, the multimedia controls were tested, where the play sound button worked appropriately after activation. Finally, the close/back button was also tested, where it successfully closed the current page and navigated back to the previous page.

C. AR Interaction and Responsiveness Analysis

The performance of AR Earth Explorer in terms of the plane detection stability, object anchoring, touch sensitivity, and user interface rendering was investigated.

Feature	Observation
AR Plane Detection	Successful
Earth Placement Stability	High
Country Selection Accuracy	Accurate
UI Response Time	Fast
Audio Playback	Functional
Mobile Performance	Smooth

Table I: System Performance Evaluation of the Proposed AR Earth Explorer

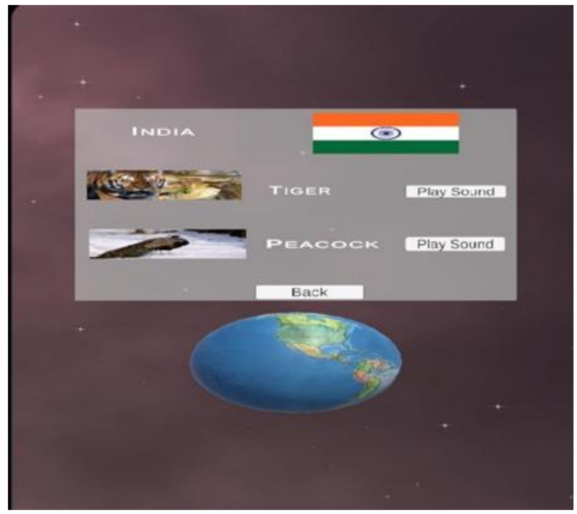

Fig. 2: Functional validation output for India.

For instance, the output of India shows that the application was able to fetch all the required multimedia information related to India such as its flag, national animal, national bird, and control button for audio playback.

The test successfully detected horizontal planes in the real world under usual indoor lighting conditions and allowed the stable positioning of the three-dimensional Earth model. The model showed minimal positional drift while moving moderately, thus providing an effective AR experience. User touch interaction with the country cube was found responsive and error-free, where the AR system could detect user touch inputs and present information panels effectively. The delay between the country cube touch event and the appearance of the UI panel was sufficiently low to facilitate real-time interaction. Aside from the interaction efficiency, the system could render smoothly all visualizations, including Earth, countries, and media elements. The integration of the user interface component was also found seamless, without any perceptible delay. The system could play audio when activated. Overall, the findings suggest that the system offers a stable AR interaction experience with acceptable responsiveness for educational exploration.

D. System Module Contribution Analysis

Efficacy of the whole system depends on the synchronized working of different functional modules, each playing an important role in providing stable visualizations, interactions, and efficient transmission of relevant data during the use of the augmented reality technology.

Firstly, the Input Layer is responsible for collecting the real environment data from the device camera, as well as processing the user's touch interactions, being the starting point for AR scene interpretation and further exploration of it. The function of the AR Foundation layer includes detecting planes and objects, as well as handling anchors, which helps stabilize the position of the virtual Earth model.

Scene and Object Management Layer can be described as a core of the system. It renders the 3D model of the Earth and creates country cubes by using the latitude-longitude map. The purpose of the Data and Metadata Layer is storing the country specific information and handling data retrieval through the use of CSV processing and placement scripts.

Interaction Controller detects the touch interactions and performs raycasting, making it possible for users to pick the selected countries accurately. Then,the chosen country triggers the presentation of relevant information in the UI and Experience layer, which displays flags, national animals, and national birds. Finally, Output Layer merges AR scenes and UI elements, offering a full learning experience for the user.

E. Multimedia Information Retrieval and Content Validation

The feasibility of AR Earth Explorer system was analyzed with regard to its ability to obtain and show multimedia data about particular countries dynamically. After clicking on a cube representing a certain country on the virtual map, the system always showed a panel with educational data about that country, which included such components as the country name, flag, animal, and bird. Therefore, the correctness of the developed mechanism for retrieving the data can be proven.

Several countries have been considered. For examples such as India, China, and Japan, the system managed to show relevant data with minimum delays. Thus, it can be stated that there is no problem in interaction between metadata layer and UI layer.

Furthermore, the possibility of obtaining audio data about selected countries was checked. The system behaved correctly in the situation when the button associated with the image of animal/bird was clicked. Thus, both visual and auditory content contributed to increased user interactivity and the educational value of the app.

F. End-to-End AR Interaction Workflow

The whole pipeline of the proposed AR (augmented reality) Earth Explorer application has been verified by testing the complete interaction sequence, from the initialization of the Augmented Reality scene to the delivery of the multimedia information. The application successfully executed all major stages of the system in sequence, including AR environment setup, Earth model placement, country cube interaction, the information retrieval, and user interface rendering.

At the beginning of execution, the system initialized the AR scene and loaded the 3D Earth model along with the interactive country cubes. When a user tapped on a country cube, the country information handler was triggered and the corresponding user interface panel was displayed. The

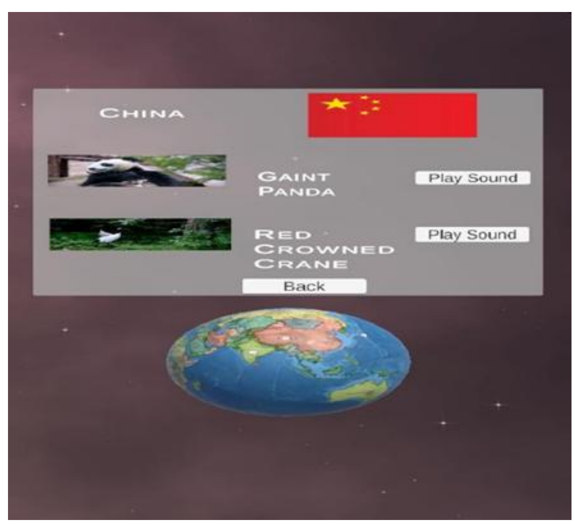

Fig. 3: China multimedia output. The output for China demonstrates the successful retrieval and display of country-specific multimedia content,

including the national flag, national animal, national bird, and interactive audio playback controls, thereby improving user engagement and educational understanding during exploration, with effective integration.

Displayed panel contained multimedia elements such as the national flag, national animal, national bird, and interactive sound controls. If the user selected the play sound option, the corresponding audio was triggered successfully, after which the system continued to remain active for further interaction. From the results, it is clear that the proposed AR Earth Explorer application provides an effective platform that allows the integration of AR visualization and interaction, multimedia rendering, and information provision within the application environment.

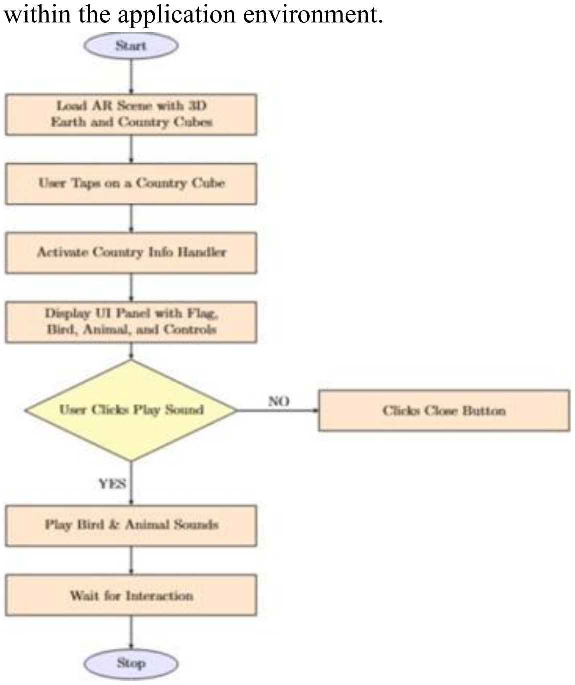

Fig. 4: Flowchart of the end-to-end interaction workflow of the proposed AR Earth Explorer system. The flowchart shows the complete process beginning from AR scene initialization and Earth model loading to country selection, multimedia information display, audio interaction, and continued user exploration.

V. CONCLUSION

The proposed system can be viewed as an immersive and educational platform that allows for the examination of geographical and cultural data in an organized and engaging fashion. Specifically, this approach features an incorporation of a 3D model of Earth into the AR environment, allowing users to interact with countries depending on their location on the map. When a particular country is selected by the user, the system automatically displays relevant media data including the flag of the country, its national animal and national bird. Implementation of the discussed system relies on Unity, AR Foundation, and XR Interaction Toolkit, allowing users to have a real-time visualization of geographical data as well as interact with the presented information using mobile devices in an effective manner. As a result, the system represents a practical example of how the AR can be used as an educational tool providing for an engaging exploration of world geography and cultural heritage. Thus, in conclusion, the discussed paper highlights the role of augmented reality in creating intuitive and context sensitive learning environments. The implemented framework demonstrates an innovative way to explore geographical data and serves as a basis for the development of future AR applications.

VI. LIMITATIONS

Though providing users with an immersive interactive AR experience, the suggested Interactive Augmented Reality Earth Exploration System has some limitations. Functionality of the system is sensitive to environment settings that may influence AR plane recognition and proper object placement, especially low light conditions, reflections, lack of texture. In addition, functionality of the system depends on the processing capacity of the device used for running the application, while lower-end devices may face some challenges in this aspect. The system works under limited number of countries and multimedia files, which limits scalability potential. In addition, the system relies mainly on the touch screen interface and does not provide other methods of interaction, like gestures and voice commands.

VII. FUTURE WORK

The future enhancements of the proposed Interactive AR Earth Exploration System can be summarized as follows:

1) Expansion of Country and Cultural Dataset

The system can be further developed by including more countries, sites, monuments, cultural markers, and also additional educational material. With such an approach, there will be more informative exploration for the user of the system.

2) Integration of Advanced Interaction Techniques

For future releases of the app, gesture control, voice command, and gaze-based interactions can be included to make them feel more natural and intuitive for the user.

REFERENCES

[1] S. Poudel and P. Poudyal, “Classification of waste materials using CNN based on transfer learning,” in *Proc. Forum for Information Retrieval Evaluation (FIRE ’22)*, Kolkata, India, Dec. 2022, pp. 1–5.

[2] M. Łysakowski, K. Zywanowski, A. Banaszczyk, M. R. Nowicki, P. Skrzypczyński, and S. K. Tadeja, “Real-time onboard object detection for augmented reality: Enhancing head-mounted display with YOLOv8,” *arXiv preprint arXiv:2306.03537*, 2023.

[3] S. Kim, J. Park, and H. Lee, “Augmented reality for data visualization in urban planning: Challenges and opportunities,” *Computers, Environment and Urban Systems*, vol. 88, Art. no. 101655, 2021.

[4] S.-E. Laidoudi, M. Maidi, and S. Otmane, “Real-time indoor object detection based on hybrid CNN-transformer approach,” *arXiv preprint arXiv:2409.01871*, Sep. 2024.

[5] B. Gururaj, S. R. Vernekar, D. S. Shreevatsa, L. Kumar, and G. Kalnoor, “Object detection using Flying Dino in augmented reality,” in *2024 International Conference on Emerging Technologies in Computer Science for Interdisciplinary Applications (ICETCS)*, 2024, pp. 1–6.

[6] D. Sahu, Nidhi, S. Prakash, V. K. Pandey, T. Yang, R. S. Rathore, and L. Wang, “Edge assisted energy optimization for mobile AR applications for enhanced battery life and performance,” *Scientific Reports*, vol. 15, Art. no. 10034, Mar. 2025.

[7] D. Gavgiotaki, S. Ntoa, G. Margetis, K. C. Apostolakis, and C. Stephanidis, “Gesture-based interaction for AR systems: A short review,” in *Proc. 16th Int. Conf. Pervasive Technologies Related to Assistive Environments (PETRA ’23)*, Corfu, Greece, Jul. 2023, pp. 1–9.

[8] M. A. Maneli and O. E. Isafiade, “A comparative evaluation of augmented reality frameworks: A plane mapping and resource utilisation perspective,” in *2023 IST-Africa Conference (IST-Africa)*, 2023, pp. 1–9.

[9] Y. Lu and L. Yihao, “Interactive augmented reality application design based on mobile terminal,” in *2021 IEEE 5th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC)*, vol. 5, 2021, pp. 63–67.

[10] S. G. Sundaram, A. Ponmalar, S. Deeba, J. Anand A., Aarthi S., and Shwetha S., “Plane detection and product trial using augmented reality,” in *2022 1st International Conference on Computational Science and Technology (ICCST)*, 2022, pp. 887–892.

[11] W.-X. You, C.-S. Huang, K.-M. Hu, T.-H. Liu, and K.-T. Lai, “Augmented reality for real object detection,” in *2023 International Conference on Consumer Electronics-Taiwan (ICCE-Taiwan)*, 2023, pp. 803–804.

[12] B. R. Maran, L. Giridharan, and R. Krishnaveni, “Augmented reality based indoor navigation using Unity engine,” in *2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS)*, 2023, pp. 1696–1700.

[13] L. M. Daling and S. J. Schlittmeier, “Effects of augmented reality-, virtual reality-, and mixed reality-based training on objective performance measures and subjective evaluations in manual assembly tasks: A scoping review,” *Human Factors*, vol. 66, no. 2, pp. 589–626, 2024.

[14] B. Du, J. Guo, J. Guo, L. Wang, and X. Li, “A rapid oriented detection method of virtual components for augmented assembly,” *Expert Systems with Applications*, vol. 235, Art. no. 123357, 2024.

[15] W.-X. You *et al.*, “Augmented reality advancements in object detection systems,” *IEEE Access*, vol. 12, pp. 1–12, 2025.