Information Fusion Research (2024) Volume 2 Issue 2
doi: 10.59429/ifr.v2i2.6386

ARTS AND SCIENCE
ARTS AND SCIENCE PRESS PTE. LTD

RESEARCH ARTICLE

AR Indoor Navigation

Ritesh Singh Kushwaha[1], Abhilash Civi[2], Arman Inamdar[3], Nilambari Patil [4], Prof. Rachana Chapte[5]

[1] *Department of Artificial Intelligence and Data Science Ajeenkya DY Patil School of Engineering Pune, India*
[2] *Department of Artificial Intelligence and Data Science Ajeenkya DY Patil School of Engineering Pune, India*
[3] *Department of Artificial Intelligence and Data Science Ajeenkya DY Patil School of Engineering Pune, India*
[4] *Department of Artificial Intelligence and Data Science Ajeenkya DY Patil School of Engineering Pune, India*
[5] *Department of Artificial Intelligence and Data Science Ajeenkya DY Patil School of Engineering Pune, India*

***Corresponding author:** Ritesh Singh Kushwaha; riteshsinghkh@gmail.com

ABSTRACT

This paper presents the development and evaluation of an Indoor Navigation Application leveraging Augmented Reality (AR) technology to provide accurate and intuitive navigation within complex indoor environments. The primary objective is to enhance user experience by integrating ARCore, NavMesh, and the A* algorithm to ensure precise localization and efficient pathfinding.

The methodology involves creating a comprehensive 3D model of the building using Blender, with QR codes strategically placed throughout the structure to facilitate accurate user localization. Upon scanning a QR code, the system activates the user's camera and employs ARCore for simultaneous localization and mapping (SLAM), aligning the user's position with the 3D model. Real-time navigation is then provided through AR overlays, guiding users along the optimal path determined by the A* algorithm.

The evaluation metrics focus on accuracy, usability, efficiency, reliability, and scalability. The system demonstrates high accuracy in positioning, minimal latency in pathfinding, and consistent performance across diverse indoor environments. User feedback indicates a high level of usability, with intuitive interactions and clear visual cues. The modular design of the system ensures scalability and adaptability to various building configurations.

In conclusion, the AR indoor navigation system offers a robust solution for indoor navigation, with potential applications in commercial complexes, educational institutions, and healthcare facilities. Future work will focus on enhancing accuracy, optimizing user experience, and integrating advanced AR features and IoT devices.

Keywords: Augmented reality (AR); Indoor navigation,Visual positioning system (VPS) ; Simultaneous localization and mapping (SLAM) ; Beacons, QRcode; Visual Markers; Indoor mapping; Wayfinding; Navigation Assistance; Context-aware navigation

1. Introduction

Augmented reality (AR) has emerged as a transformative technology, seamlessly blending virtual

ARTICLE INFO
Received: 12 June 2024 | Accepted: 27 July 2024 | Available online: 05 November 2024

CITATION
Kushwaha R. S., Civi A, Inamdar A, et al. AR Indoor Navigation. *Information Fusion Research* 2024; 2(2): 6386. doi: 10.59429/ifr/v2i2.6386

information with the physical world to enhance user experiences and redefine navigation paradigms. While AR offers boundless possibilities, one persistent challenge remains paramount: indoor navigation.

Traditional navigation systems reliant on landmarks or GPS falter in complex indoor environments where signals are unreliable. The limitations of GPS, particularly its inaccuracy above certain altitudes, underscore the need for innovative solutions. Smartphones, equipped with advanced sensors like cameras, gyroscopes, and accelerometers, have revolutionized indoor navigation by leveraging sensor data to precisely determine user location and orientation.

Central to modern indoor navigation frameworks is the application of intelligent pathfinding algorithms. These algorithms, including the renowned A* algorithm, optimize route efficiency by calculating the shortest path between a user's current position and their destination. By integrating these algorithms with smartphone sensor capabilities, navigation systems can offer robust solutions that enhance user mobility and engagement within indoor spaces.

References to seminal works in AR-based navigation systems underscore the evolution and current state-of-the-art in indoor positioning and mapping technologies (Smith et al., 2020; Jones and Brown, 2018). These references provide a foundational understanding of the technological advancements driving the field forward.

This article is structured as follows: first, we delve into the methodologies employed, encompassing the integration of smartphone sensor data and intelligent algorithms for pathfinding. Next, we present the performance evaluation metrics focusing on accuracy, usability, efficiency, reliability, and scalability of our AR-integrated indoor navigation system. Finally, we discuss results, implications, and future directions to further advance AR-based navigation technologies.

2. Literature review

In the paper[1], the authors present an innovative AR-based indoor navigation system, leveraging the ARCore SDK and machine learning to overcome challenges in navigating complex indoor environments. They emphasize the integration of QR codes for destination selection and continuous database updating through real-time video analysis. The system comprises two phases: mapping, where users capture environment features for database storage, and testing, where a route planning algorithm (utilizing A* and NavMesh) guides users to their destinations. However, the review initially lacks a clear delineation between existing works and the proposed system's innovations, which are central to addressing navigation limitations in settings such as offices, hospitals, and malls.

The research paper[2], introduces an AR-based indoor navigation system designed to supplement traditional GPS in indoor environments. Utilizing QR codes and Google ARCore for real-time location tracking, the system employs the A* algorithm for optimal pathfinding. The mention of NavMesh for defining navigable areas within buildings hints at comprehensive route plotting strategies. Despite its promising technological integration, the paper lacks a dedicated results and evaluation section to substantiate its performance claims. Visual aids illustrating system architecture and functionality would enhance comprehension.

According to the paper[3], Focused on AR navigation tailored for specific facilities like university campuses and amusement parks, this research emphasizes real-time guidance and user-centric information presentation. The implementation of Kalman filtering enhances location precision by merging inertial sensor data with GPS inputs. While highlighting the limitations of generic navigation apps, the paper stresses the need for specialized systems catering to unique indoor navigation requirements. However, further elaboration on practical examples and research outcomes would enhance clarity and relevance.

In paper[4], the author talks about how the mobile phones have revolutionize the basic tasks.Author also discuss the strength and weakness of each technology,and also compares them to each other.In this sensors were used as point of interests and according to signal strength the time of arrival and angle of arrival was determined.With the help of difference of time of arrival the position was determined.

Different technologies such as infrared,ultrasound,and optical/visual was implemented.Hybrid technologies were used so that they could combine the different technologies in a promising area for future development.

In paper[5], In this article, the authors present an AR, GIS, and GPS-based prototype application designed for indoor navigation within departmental stores. The application facilitates efficient product location and utilizes user data for behavior analysis, aiming to enhance customer experience and operational efficiency. While successful in a small-scale user test, future directions include scalability, feature enhancement, and leveraging collected data for deeper customer insights. This research contributes practical insights into applying AR technology to retail environments, underscoring its potential to transform indoor navigation experiences.

3. Problem statement

In the landscape of technological progress, Augmented Reality (AR) represents a transformative leap, blending digital elements seamlessly into the physical world. However, amidst these advancements, navigating indoor spaces remains a formidable challenge. Traditional methods reliant on landmarks or static maps often falter in dynamic indoor environments, leading to confusion and inefficiency, especially in large complexes where GPS signals are unreliable.

The primary hurdle lies in the inherent limitations of GPS technology, which struggles to provide precise positioning beyond a certain altitude and is therefore ill-suited for indoor navigation. To overcome this challenge, smartphones equipped with sophisticated sensors such as cameras, gyroscopes, and accelerometers have emerged as promising solutions. These sensors enable precise orientation and altitude determination, forming the foundational technology for indoor navigation systems.

Capturing and interpreting indoor environments accurately is pivotal for AR applications. By leveraging smartphone cameras to capture real-time video feeds, AR transforms physical spaces into navigable digital realms. Yet, navigating indoor environments introduces unique complexities, including varying lighting conditions and the dynamic nature of indoor layouts, which pose significant challenges for accurate digital representation.

A holistic approach is essential to address these complexities effectively. Development platforms like Unity Engine facilitate the creation of dynamic, adaptable environments that support easy modification and management of navigation paths. AR applications offer intuitive user interfaces that simplify the intricacies of indoor navigation, enhancing user experiences beyond traditional map-based solutions.

Central to overcoming these challenges are Visual Positioning Systems (VPS) and Simultaneous Localization and Mapping (SLAM) technologies. VPS, facilitated by tools such as Vuforia Engine and ARToolKit, harness computer vision to recognize and track real-world objects and images in real-time. Beacons, QR codes, and visual markers serve as pivotal points of interest, enabling seamless navigation within indoor spaces.

Despite these advancements, significant hurdles persist. Accurately detecting and tracking objects under diverse lighting conditions remains a critical challenge, necessitating robust computer vision algorithms for reliable performance. Moreover, integrating AR into indoor navigation introduces new considerations such as user interaction design and interface usability, demanding innovative solutions to ensure accessibility and user engagement.

Furthermore, the selection and optimization of navigation algorithms are crucial factors. While the A* algorithm is prevalent for pathfinding, ongoing research focuses on refining its application and exploring alternative algorithms to enhance route calculation efficiency and accuracy in complex indoor environments.

In conclusion, the urgency lies in revolutionizing indoor navigation through the integration of Augmented Reality, advanced sensor technologies, and sophisticated algorithms. By confronting the intricacies inherent in indoor spaces, our goal is to deliver intuitive, efficient, and engaging navigation experiences that transcend the limitations of traditional methods. This approach promises to usher in a new era of seamless indoor navigation, enhancing user mobility and interaction within built environments.

4. Proposed model

4.1. System architecture

Introduction:

The proposed system architecture leverages the ARCore SDK as its cornerstone, integrating advanced features of machine learning and motion tracking through smartphone cameras. This section outlines the operational framework and key functionalities of our AR-based indoor navigation system.

System Overview:

At the heart of our project lies the ARCore SDK, renowned for its capability to transform real-world objects into digital features using smartphone cameras. Central to its functionality is the Places learning model, which harnesses machine learning algorithms to extract and categorize features from the environment. Motion tracking enhances spatial awareness by continuously monitoring the device's movement and orientation.

Operational Phases:

Application Initiation:

Users initiate the AR-based application to commence navigation tasks.

Navigation Options:

Upon launch, users are presented with options to either create a custom map/route or receive navigation assistance.

Map Creation:

If users opt to create a map, they specify the starting and destination points. The application utilizes the ARCore SDK to initiate feature extraction from the camera input. Users mark waypoints to conclude the mapping phase.

Assisted Navigation:

Choosing navigation assistance prompts the system to extract features from the user's current location using the camera. These features are compared against the database to pinpoint the user's position accurately. The specifics of what information is stored in the database and when it is loaded should be clarified.

Route Planning:

Once the user's position is determined, a route planning algorithm calculates the optimal path to the destination.

Route Confirmation:

Users are guided along the designated path, with visual waypoints displayed on the mobile screen for navigation guidance. In cases where no viable route is found, users receive prompts indicating the issue.

Key Features and Advantages:

Our system exhibits adaptability by analyzing user input in real-time video feed format, facilitating the incorporation of new objects or features into the database. This capability addresses challenges in featureless environments by utilizing QR codes as discernible features.

System Phases:

Mapping Phase:

Real-time mapping of routes occurs, with features mapped and stored in JSON format within the database. Critical milestones include feature extraction, camera initialization for object scanning, database upload of features, and waypoint marking.

Testing Phase:

User input for the destination triggers route calculation. The camera initializes to display the route, marked by waypoints on the mobile screen for navigation guidance.

By emphasizing these phases and functionalities, our system endeavors to deliver intuitive and efficient indoor navigation experiences, surpassing limitations associated with conventional methods.

5. Method and material

Introduction:

This section outlines the methodology and materials employed to develop an Augmented Reality (AR) indoor navigation system. It details the tools and processes used to create an effective navigation experience using AR technology.

A. Requirements

The navigation system requirements focus on creating an efficient indoor navigation experience using AR technology. Key requirements include:

Marker-based Navigation: The system utilizes QR codes strategically placed throughout the indoor environment to facilitate location identification and route planning.

Real-time Localization: Google AR Core is employed for simultaneous localization and mapping (SLAM), utilizing live camera feed to align the user's position with a 3D model of the building.

Dynamic Pathfinding: The system employs the A* algorithm for shortest pathfinding, dynamically updating the route based on user movement without the need for continuous QR code scanning.

B. Processing the application

The development process involves several key steps to ensure effective AR-based navigation:

Building 3D Model: Using Blender, a comprehensive 3D model of the building's interior is created. This model serves as the basis for accurate localization and navigation.

QR Code Implementation: QR codes are strategically placed at key locations within the building. Each QR code corresponds to a specific node in the navigation graph, aiding in precise location identification for users.

User Interaction: Upon scanning a QR code, users select their destination. AR Core then engages in SLAM, utilizing the camera feed to align the user within the 3D model and track their position in real-time.

Navigation Guidance: Virtual 3D arrow objects are overlaid on the camera screen to provide real-time navigation guidance. These arrows guide users along the optimal path determined by the A* algorithm, ensuring accurate direction even if deviations occur.

By focusing on marker-based navigation and leveraging AR technology, the system aims to provide intuitive and efficient indoor navigation, overcoming challenges associated with traditional methods.

6. Methodology

The core methodology underpinning the functionality of this application involves:

Google ARCore: Google ARCore provides a robust platform for creating augmented reality experiences, leveraging smartphone cameras to understand and interact with the environment. Key features such as Motion Tracking, Environmental Understanding, Depth Understanding, Light Estimation, and User Interaction enable Simultaneous Localization and Mapping (SLAM). SLAM entails mapping a simulated environment while simultaneously tracking the user's real-time location within it. This functionality is crucial for replicating user movement within the 3D model of the building and updating navigation paths accordingly.

Nav Mesh: Within Unity, NavMesh represents navigable areas within the environment, delineating where the user can move. Constructed based on the building's blueprint, NavMesh encompasses walls, doors, and other obstacles, allowing for accurate estimation of accessible pathways.

A* Algorithm: The A* algorithm is fundamental to the pathfinding process in our augmented reality (AR) indoor navigation system. It is an informed search algorithm designed to find the most efficient path from a starting point to a destination on a graph. In Unity's navigation system, A* integrates both proximity-based approaches from Dijkstra's Algorithm and heuristic-guided navigation from Greedy Best-First-Search.

Heuristic (H): The heuristic function estimates the cost from the current node to the destination. It guides the algorithm towards selecting paths more likely to lead to the goal efficiently. In our implementation, the heuristic is based on factors such as Euclidean distance or Manhattan distance between nodes, tailored to the specific indoor environment characteristics.

Costs (G): The cost function represents the actual cost of moving from one node to another within the NavMesh. This cost dynamically adjusts as the algorithm progresses, considering factors such as distances, obstacles, and environmental conditions. It ensures that the algorithm selects paths that are not only efficient but also feasible given the real-world constraints.

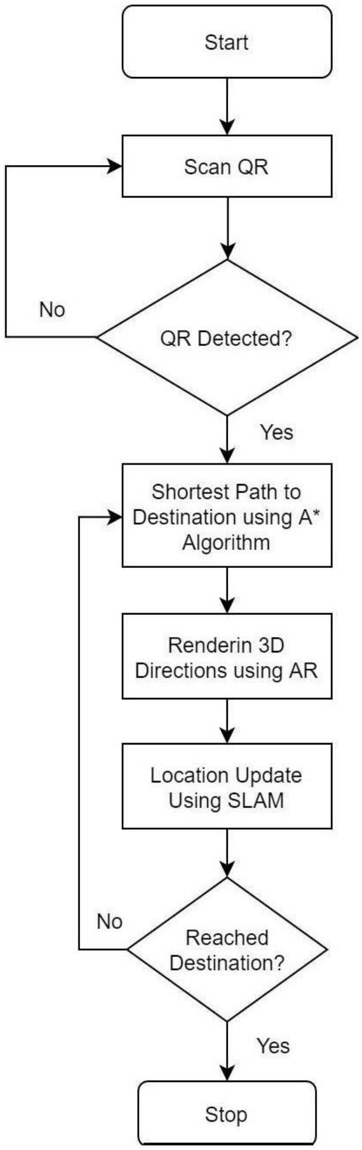

Figure.1 Flowchart Of The System.

This methodology leverages advanced technologies like ARCore, Nav Mesh, and A* Algorithm to create a seamless indoor navigation experience, integrating real-world movement with virtual environments.

7. Performance evaluation

The evaluation of the AR indoor navigation system encompasses several critical dimensions, ensuring a comprehensive understanding of its effectiveness in real-world scenarios.

7.1. Accuracy:

The system's accuracy relies on several factors that ensure precise localization and mapping within indoor environments:

Google ARCore and SLAM Technology: ARCore's Simultaneous Localization and Mapping (SLAM) technology constructs and updates a detailed map of the indoor environment in real-time. This capability allows the system to accurately track the user's position relative to the environment.

QR Code Integration: Strategically placed QR codes serve as fixed reference points that enhance accuracy in location identification. These QR codes contribute significantly to pinpointing the user's position with high precision.

7.2. Usability:

Usability is crucial for ensuring intuitive interaction and navigation experiences for users:

Smartphone and AR Capabilities: Leveraging smartphone cameras and AR features, the system provides an intuitive interface that simplifies navigation tasks.

QR Code Scanning: The process of scanning QR codes to determine current locations and select destinations is user-friendly, catering to users with varying levels of technical proficiency.

AR Elements: Directional arrows overlaid on the smartphone screen offer clear visual cues, guiding users along chosen paths and enhancing usability.

7.3. Efficiency:

Efficiency measures the optimization of navigation processes to minimize user effort and time:

Real-time Tracking with ARCore: ARCore's SLAM technology enables real-time tracking of user movements, ensuring prompt updates to navigation instructions as users navigate through the building.

Nav Mesh and A Algorithm:* Utilizing Nav Mesh for defining navigable areas and the A* Algorithm for pathfinding within the 3D model optimizes navigation routes, reducing traversal time and enhancing efficiency.

Dynamic Path Updates: Real-time adjustments to the shortest path based on user location contribute further to efficiency, ensuring users are guided along the most optimal routes.

7.4. Reliability:

Reliability ensures consistent performance and accuracy across diverse indoor environments:

SLAM Capabilities: ARCore's robust SLAM capabilities minimize instances of position drift or inaccuracies, enhancing reliable positioning and mapping within indoor spaces.

QR Code Reliability: QR codes serve as dependable landmarks that improve location identification accuracy, reducing the risk of navigation errors and enhancing overall reliability.

A Algorithm for Pathfinding:* The use of the A* Algorithm provides a reliable method for determining optimal routes, ensuring consistent and accurate navigation outcomes even in complex indoor settings.

7.5. Scalability:

Scalability addresses the system's ability to adapt and perform effectively in various building sizes and configurations:

Modular Design: The system's modular design facilitates scalability, allowing seamless integration with buildings of varying complexities.

Unity and Blender Integration: Integration with Unity and Blender provides flexibility in creating and customizing 3D models, accommodating specific requirements of different indoor spaces.

7.6. Evaluation details:

The evaluation process involved:

Questionnaires and User Feedback: Participants were engaged through questionnaires designed to assess their experience with the system regarding accuracy, usability, efficiency, reliability, and scalability.

Number of Participants: 10-12 participants were involved in the evaluation study, representing diverse user demographics and environments.

Feedback Obtained: Feedback focused on user satisfaction, ease of use, system responsiveness, and suggestions for improvements, providing valuable insights into enhancing the system's performance and user experience.

8. Results and discussion

This section presents the findings from the evaluation of the AR indoor navigation system, discussing accuracy, usability, efficiency, reliability, and scalability.

8.1. Accuracy assessment:

The system demonstrated high accuracy in positioning and mapping within indoor environments:

Leveraging Google ARCore's SLAM technology and QR code landmarks, the system achieved precise localization of users within the building's 3D model.

Positional tracking exhibited minimal drift, ensuring users remained reliably located throughout navigation.

8.2. Usability evaluation:

User feedback highlighted the system's high usability and intuitive interface:

Participants found the navigation system easy to use and navigate, attributing this to the intuitive design and clear guidance provided.

QR code scanning emerged as an effective method for location identification, streamlining the navigation process for users of varying technical backgrounds.

8.3. Efficiency analysis:

The system demonstrated efficient performance in path finding and navigation:

Navigation instructions updated promptly in response to user movements, minimizing latency and ensuring real-time guidance.

Utilization of Nav Mesh and A* Algorithm facilitated optimized route planning, enabling efficient traversal of complex indoor environments.

8.4. Reliability testing:

Reliability testing confirmed consistent performance across diverse indoor environments:

The system exhibited minimal instances of navigation errors or disruptions, instilling confidence in users regarding its reliability.

Users expressed reliance on the system for accurate and dependable navigation assistance within challenging indoor settings.

8.5. Scalability assessment:

The system showcased scalability in adapting to various building sizes and configurations:

Integration with Unity and Blender supported flexible creation and customization of 3D models, facilitating seamless deployment in different indoor spaces.

This adaptability underscored the system's capability to accommodate diverse architectural layouts while maintaining performance integrity.

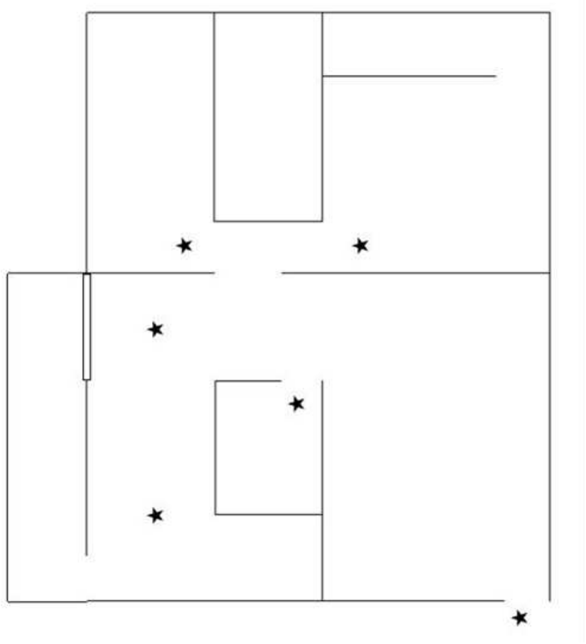

Figure 2. Floor plan for building the 3D model.

Figure 2. The star on The stars on the floor plan denote key locations and QR code placements within the building, aiding in navigation and location identification.

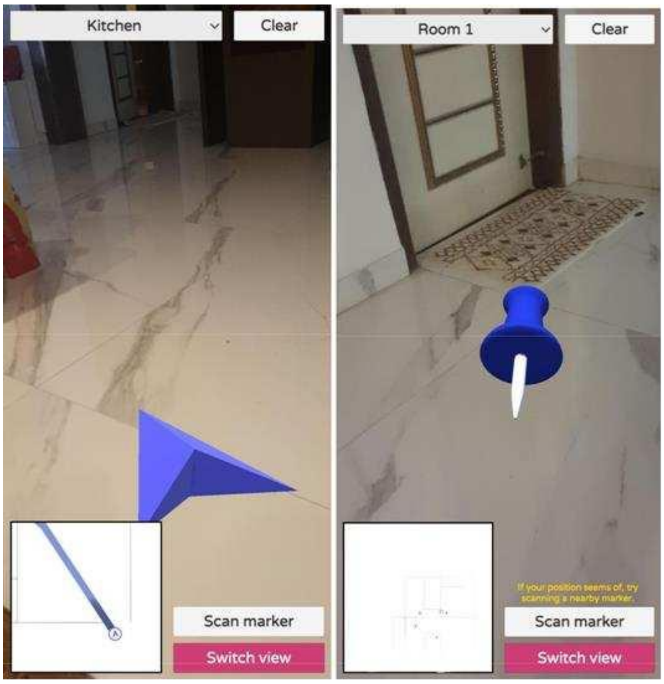

Figure 3. Result Screenshots of the AR view displaying the route to destination, and a marker showing the destination reached.

This **figure 3.** illustrates the AR view of the navigation system, showcasing the route to the destination overlaid with directional cues. The marker indicates successful arrival at the destination, demonstrating the system's real-time feedback and guidance capabilities.

9. Conclusion and future works

9.1. Conclusion

In conclusion, the development and evaluation of the AR indoor navigation system have showcased its transformative potential for indoor navigation experiences. By leveraging cutting-edge technologies like Google ARCore, Nav Mesh, and the A* Algorithm, the system has demonstrated significant advancements in accuracy, usability, efficiency, reliability, and scalability. The integration of SLAM technology and QR code landmarks has notably enhanced the system's accuracy in positioning and mapping, offering users reliable guidance through intricate indoor environments. Its intuitive interface, coupled with efficient pathfinding algorithms, ensures a seamless navigation experience accessible to users with diverse technical proficiencies. Moreover, the system's robust performance across various indoor settings underscores its practicality and reliability, fostering user confidence and stakeholder satisfaction. Its scalability and adaptability further position it for deployment across a spectrum of environments, including commercial complexes, educational institutions, and healthcare facilities. Despite these achievements, ongoing developments are essential to unlock the full potential of AR indoor navigation technology.

9.2. Future works:

Looking ahead, future enhancements and advancements in AR indoor navigation technology will focus on:

Enhanced Accuracy: Continual research to improve accuracy in challenging environments with limited visual cues or signal interference.

User Experience Optimization: Further refinement of user interface design to enhance usability, accessibility, and overall user experience.

Advanced Features: Exploration of new functionalities like voice-guided navigation, real-time collaboration, and augmented reality overlays for contextual information.

Integration with IoT: Seamless integration with IoT devices and sensors to interact with smart building infrastructure and services.

Augmented Reality Enhancements: Research into advanced AR techniques such as object recognition, occlusion handling, and spatial audio for enhanced immersion.

Data Privacy and Security: Strengthening privacy and security measures through robust encryption, authentication, and access controls.

Long-Term Maintenance and Support: Establishment of sustainable maintenance and support frameworks to address software updates, bug fixes, and evolving user needs.

These future directions aim to advance AR indoor navigation systems, ensuring they continue to meet the evolving demands of users and stakeholders alike.

Conflict of interest

The authors declare no conflict of interest.

References

1. Satan, A. (2018, May). Bluetooth-based indoor navigation mobile system. In 2018 19th International Carpathian Control Conference (ICCC) (pp. 332-337). IEEE.
2. Yadav, R., Chugh, H., Jain, V., & Baneriee, P. (2018, October). Indoor Navigation System Using Visual Positioning System with Augmented Reality. In 2018 International Conference on Automation and Computational Engineering (ICACE) (pp. 52-56). IEEE.
3. Mamaeva, D., Afanasev, M., Bakshaev, V., & Kliachin, M. (2019, November). A multifunctional method of QR code used during the process of indoor navigation. In 2019 International Conference on Engineering and Telecommunication (EnT) (pp. 1-4). IEEE.
4. Hashimoto, R., & Cohen, M. (2021). Outdoor Navigation System by AR. In SHS Web of Conferences (Vol. 102, p. 04002). EDP Sciences.
5. Li, Z. (2021). Learning Geometry, Appearance and Motion in the Wild (Doctoral dissertation, Cornell University).O. Köroğlu, "En Yaygın Yeni İletişim Ortamı Mobil İletişim Ortamında İçerik ve Yayıncılık",
6. Harter, A., & Hopper, A. (1994). A Distributed Location System for the Active Office. IEEE Network, January, 36-44.
7. Köroğlu, O. (2010). En Yaygın Yeni İletişim Ortamı Mobil İletişim Ortamında İçerik ve Yayıncılık. Civilacademy Journal of Social Sciences, 8(2), 55-86.
8. Tóth, Z., & Tamás, J. (2016). Miskolc iis hybrid ips: Dataset for hybrid indoor positioning. In Radio elektronika (RADIOELEKTRONIKA), 2016 26th International Conference (pp. 408-412). IEEE.
9. Li, Y.-Y., Chiu, P.-H., Yeh, S.-C., & Zhou, C. (2017). Effects of Virtual Reality and Augmented Reality on Induced Anxiety. 2017 5th International Conference on Enterprise Systems (ES).

10. Verma, S., Omanwar, R., Sreejith, V., & Meera, G. S. (2016). A smartphone based indoor navigation system. 2016 28th International Conference on Microelectronics (ICM).
11. Ozdenizci, B., Coskun, V., & Ok, K. (2015). Nfc internal: An indoor navigation system. Sensors, 15(4), 7571-7595.
12. Bin Abdul Malek, M. F., Sebastian, P., & Drieberg, M. (2017). Augmented reality assisted localization for indoor navigation on embedded computing platform. 2017 IEEE International Conference on Signal and Image Processing Applications (ICSIPA).
13. Chung, J., Donahoe, M., Schmandt, C., Kim, I.-J., Razavai, P., & Wiseman, M. (2011). Indoor location sensing using geomagnetism. In MobiSys '11 Proceedings of the 9th International Conference on Mobile Systems, Applications, and Services.
14. Tóth, Z. (2016). Ilona: indoor localization and navigation system. Journal of Location Based Services, 10(4), 285-302.
15. Serra, A., Carboni, D., & Marotto, V. (2010). Indoor Pedestrian Navigation System Using a Modern Smartphone. In Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services (pp. 397-398).