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RESEARCH ARTICLE

From GPS to AR: Leveraging Augmented Reality and Grid-Based Systems for Improved Indoor Navigation

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ABSTRACT With the rapid growth of technology in intelligent city networks, navigating inside complex buildings has become increasingly difficult. The indoor Global Positioning System (GPS), which operates within an ultra-high radio frequency range, suffers from signal degradation due to thick walls. The lack of GPS signals and the inability to maintain a line of sight with orbiting satellites make indoor navigation more challenging than outdoor environments. Although Radio Frequency (RF) signals, Assisted GPS, and sensor-based solutions are used to track users indoors, they each have limitations. This paper introduces the Enhanced Smart Indoor Navigation System Using Augmented Reality (ESINS_AR), which offers a solution to these challenges using available and accessible resources. ESINS_AR facilitates easy location of places like shops within shopping malls, specific hotel rooms, or university lecture rooms by providing users with reasonably accurate visual assistance through their smartphones. Inspired by Augmented Reality (AR) and 2-D visual markers, the system uses several markers throughout the building. When scanned using the application, these markers display arrows on the screen, guiding users to their destination. The application allows users to select and change their desired destination as needed.

INDEX TERMS Augmented reality, global positioning system, indoor navigation, radiofrequency.

I. INTRODUCTION

The global community is currently concerned with the growth of smart cities and the emergence of novel techniques resulting from information technology advancements. Consequently, "Modern issues necessitate modern solutions." Due to the Internet of Things (IoT) expansion and business opportunities, indoor navigation systems have been implemented in numerous large buildings, including hospitals, retail centers, train stations, and government buildings.

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The term "Indoor Navigation System" [1] refers to a device that monitors the user's location, devises plausible routes, and directs the user along the path to the desired destination, as shown in Figure 1. In the present day, it is imperative to have an indoor navigation system to facilitate the navigation of individuals unfamiliar with the facility's map within the structure without encountering any obstacles. Outdoor navigation systems that rely on positioning technologies such as the Global Positioning System (GPS) will not be effective.

Federated Learning (FL) offers transformative potential for developing efficient and privacy-preserving indoor navigation systems, particularly within Industry 4.0 environments

FIGURE 1. Indoor navigation system.

and Beyond 5G (B5G) networks, as highlighted in [2]. By leveraging FL, collaborative model training is possible without sharing raw data, ensuring user privacy and data security in applications such as localization, navigation, data sharing, and human activity recognition. This decentralized approach is especially beneficial in addressing the growing reliance on distributed data sources, such as IoT devices and smart sensors, which are central to modern indoor navigation systems. However, employing FL in such environments presents several challenges, including substantial privacy and security concerns, such as differential privacy leaks and back-door poisoning during model updates. Robust solutions are required to mitigate these vulnerabilities and guarantee user and cloud data security. Additionally, FL must contend with resource management issues, as the varying computational capacities of mobile devices can impact the accuracy and convergence of the overall model. The heterogeneity of data and devices further complicates FL implementation in intelligent manufacturing environments, requiring adaptive algorithms to process diverse data sources effectively. Moreover, the seamless integration of FL with Industry 4.0 technologies, such as IoT and Big Data, necessitates the development of new standards and protocols. Despite these challenges, FL provides a scalable, secure, and adaptive framework, making it a critical component for advancing next-generation indoor navigation systems.

The GPS cannot provide relatively accurate tracking in indoor environments due to non-line-of-sight-related issues [3]. This constraint exacerbates the implementation of GPS in indoor navigation systems; however, it is feasible to resolve this issue by employing "high-sensitivity GPS receivers or GPS pseudolites [4]. In real-world scenarios, the implementation cost can be regarded as a substantial impediment to the practical deployment of this system. I find it more challenging to navigate indoor spaces than outdoor spaces. Different obstacles in the interior areas exacerbate the challenge of integrating navigation systems.

Navigational difficulties are exacerbated by the growing complexity of indoor environments, including hospitals, universities, and shopping centers. Conventional GPS-based systems cannot accurately position indoors because they depend on signals that cannot penetrate thick walls or maintain a line of sight with satellites. Various sensor-based solutions, such as assisted GPS and RF signals, are alternative technologies impractical for widespread adoption due to their high costs, environmental interferences, or limited accuracy.

Furthermore, indoor navigation systems often lack the flexibility to adapt to various environments, as they are frequently customized for specific buildings. This customization requirement results in substantial development efforts and high costs, as new applications must be developed practically from the beginning for each new building, which directly opposes the principle of code reusability.

The Enhanced Smart Indoor Navigation System Using Augmented Reality (ESINS_AR) is introduced in this paper as a solution to these issues. Leveraging augmented reality, ESINS_AR offers a cost-effective and intuitive indoor navigation solution. Visual markers strategically located within buildings can provide users with real-time smartphone navigation assistance. Digital navigation signals are superimposed onto the physical environment by the system, ensuring that users are directed to their destinations more efficiently.

This paper proposes ESINS_AR, which is based on other positioning technologies. To enhance the user experience for the navigation application, we implemented Augmented Reality (AR), which involves integrating digital components into the physical world as navigational arrows. This represents a significant advancement in the direction of the future.

ESINS_AR assists users in identifying their desired destinations without spending time searching for the kiosks on the maps or inquiring with those in their vicinity about the shortest routes. However, the primary issue with the current indoor navigation applications is that they are exclusive to a particular building and are tailored to function exclusively within that structure. The inflexibility of the application will result in a significant amount of cost and effort when applying it to various buildings. This is equivalent to developing the application from scratch rather than merely refactoring or altering the model. This approach fails to achieve the technology's primary objective, which is to achieve the highest efficiency and lowest cost and effort possible in the projects we participate in.

Consequently, the increasingly popular AR technology with ESINS_AR can assist users in enhancing the immersive and interactive navigation experience. The world morphs into the interface in ESINS_AR as individuals employ more intuitive controls. The user will be guided through an interior environment that is unfamiliar to them and has been configured for which the application has been designed, using direction arrows that are augmented in the real world and visible on handheld devices like smartphones.

The proposed ESINS_AR system addresses the constraints of existing indoor navigation technologies by providing a user-friendly, scalable, and adaptable solution that can be readily implemented in various indoor environments without the need for extensive redevelopment. This approach also reduces the cost and effort of deploying indoor navigation systems and improves the user experience.

As follows are the primary contributions of the paper "ESINS_AR: An Enhanced Smart Indoor Navigation System Based on Augmented Reality":

- The paper suggests an ESINS_AR that leverages AR technology and visual indicators to offer interactive and precise indoor navigation assistance.
- ESINS_AR provides a scalable and adaptable solution compared to conventional systems designed for specific structures. It can be effortlessly adjusted to indoor environments without substantial redevelopment, enhancing code reusability and decreasing implementation expenses.
- The ESINS_AR system improves user interaction and experience by incorporating augmented reality. AR overlays that display direction arrows and navigation cues enable users to navigate intricate indoor spaces using their devices, providing real-time visual guidance.
- ESINS_AR is a cost-effective alternative to existing indoor navigation solutions. It reduces the necessity for costly hardware and infrastructure modifications from using widely available smartphones and essential visual markers.
- The A* pathfinding algorithm is implemented by the ESINS_AR system, which enhances route planning by eliminating excess turns and establishing more direct routes. This improves the accuracy and efficacy of navigation in comparison to conventional methods.
- The paper contains a comprehensive performance evaluation of the ESINS_AR system, which illustrates its efficacy in terms of accuracy, response time, and runtime analysis. Comparative analyses of ESINS_AR with extant technologies emphasize its performance in various metrics.
- The proposed system is validated through real-world scenarios, including navigation within large structures like shopping malls and universities. This practical application emphasizes the system's robustness and applicability in various environments.
- By combining augmented reality with indoor navigation, ESINS_AR is a first step toward future-oriented technology that bridges the divide between the digital and physical realms, offering users a seamless and interactive navigation experience.

This document is divided into the following sections: The pertinent work is detailed in Section II. The preliminary information is presented in Section III. In Section IV, the proposed system and the system architecture are discussed. In Section V, the proposed system's performance is illustrated. Finally, the task is concluded in Section VI.

II. RELATED WORK

At present, there are a multitude of schemes that are relevant to indoor navigation systems; however, the majority of these are only partially suitable for high-precision indoor navigation systems. Smart Indoor Navigation System Using Augmented Reality was devised and implemented for indoor navigation applications in the Indoor Navigation System, Augmented Reality (SINS_AR) [5]. The SINS_AR system comprises four primary modules: AR Core-based localization, QR code repositioning, Unity NavMesh navigation [6], and AR path displaying. This system strives to ensure precision and accuracy when employing an indoor positioning system (IPS) since satellites cannot achieve a line of sight within structures [7].

This system generates a geometry utilizing the NavMesh components to facilitate pathfinding within structures. The interior navigation system is employed to ascertain the destination path through vast structures based on the current user location. The system will implement theta* pathfinding algorithm to establish the shortest route if multiple paths exist. The primary drawback of the SINS_AR system when using the theta* method to construct NavMesh is that theta* reduces path length but increases complexity when applied to NavMesh environments with dynamic obstacles or large, irregular spaces by verifying line-of-sight between nodes. The constant recalculation of line-of-sight trajectories can significantly improve computational overhead, particularly when the environment undergoes frequent changes.

In indoor environments where structures or obstacles are in motion, such as people or transient obstacles, Theta* may have difficulty maintaining a real-time pathfinding update, resulting in performance degradation. Theta* can be more computationally intensive than A* when applied to large-scale environments. Additional checks are required for every node to determine if a straight-line path between them is possible. These line-of-sight checks may become computationally expensive, especially in environments with complex geometry.

Humans or objects are within structures in the RFID Positioning Robot (RF_PR) [8]. The intended localization accuracy and precision are achieved through the use of a variety of technological methods, including cameras [9], lasers [10], sonars [11], Wi-Fi [12], Bluetooth [13], ultrawideband [14], magnetic fields [15], encoders and inertial sensors [16], [17], and Radio Frequency Identification (RFID) [18]. The RF_PR system utilizes passive RFID technology at the ultra-high frequency (UHF) band to detect tags and offer a reading range of up to ten meters.

Moreover, UHF-RFID technology facilitates the deployment of tag classification [19], [20] and tag localization features [21], [22]. UHF-RFID technology-enabled tags have been exhibited when a robot with a reader antenna travels along multiple trajectories that may not be contiguous. The UHF-RFID is highly sensitive to interference, has reduced wavelengths, and is extremely potent. This implies that the scanner's signal may be disrupted by detected objects, such as water or metal; however, mechanisms have been established to ensure that all material products can be accurately tracked using UHF technology. The wave signal of UHF-RFID is irreconcilable with the surveyed environment due to the interference of metal or water, which is one of the few drawbacks of this scheme. The UHF-RFID operates within a frequency range of 300 MHz to 3 GHz and has a reading range of 12 meters (40 feet). Scanning RFID readers with a phone is not feasible, as this is impossible with barcodes, despite the availability of fixed and remote readers. It is also necessary for the robot to transmit signals through the road as a result of its high-power consumption. This is particularly restrictive, requiring transporters or field personnel to possess specific RFID readers to conduct scans or connect RFID readers to the same robot. Cell phones cannot function as a backup if the readers provided are rendered dysfunctional.

The authors in [23] introduce an innovative indoor navigation system to enhance emergency evacuation processes. Integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS) creates a detailed indoor path network, enabling efficient navigation even in complex building layouts. The study combines Wi-Fi fingerprinting for initial user localization and Pedestrian Dead Reckoning (PDR) for real-time updates, leveraging smartphone sensors for enhanced positioning accuracy. Navigation instructions are provided through an Augmented Reality (AR) interface, superimposing directions on the user's smartphone screen to ensure an intuitive and user-friendly experience. The proposed system offers scalability by utilizing BIM data, which can be generated from 2D CAD designs and integrated with GIS for spatial analysis. It is evaluated through a System Usability Scale (SUS) test, achieving a score of 70.59, indicating above-average usability. Limitations such as reliance on single exit points and potential Wi-Fi signal inconsistencies are acknowledged, with suggestions for future research, including multi-exit considerations, congestion modeling, and integration of Artificial Intelligence (AI) for further refinement. The study highlights the potential of AR in emergency evacuation systems, emphasizing improved safety, efficiency, and user interaction.

The authors in [24] introduce an innovative solution to enhance emergency evacuations in complex indoor environments. It utilizes mobile phones as a primary interface, enabling users to navigate efficiently during emergencies by providing real-time, context-aware guidance. The system employs autonomous navigation algorithms to determine the safest and shortest evacuation routes, dynamically adapting to hazards such as blocked paths or fires. Advanced indoor positioning technologies ensure accurate user localization, addressing the limitations of GPS in indoor spaces. This user-centric system integrates seamlessly with emergency response frameworks, offering centralized monitoring and dynamic route updates to enhance safety. Simulations and controlled tests validate its effectiveness, showing significant reductions in evacuation times and improved user safety. By leveraging widely available mobile phones, the system is accessible and practical, making it a promising tool for emergency management in modern buildings.

The authors in [25] propose a novel solution to assist visually impaired individuals in navigating indoor environments. The system leverages a Wireless Sensor Network (WSN) infrastructure deployed throughout the building, which interacts with a mobile device carried by the user. By collecting and analyzing real-time location data, the system provides audio-based navigation instructions to guide the user safely and efficiently. Key features of the system include precise indoor localization using WSN nodes, which overcome GPS limitations in indoor settings, and a focus on accessibility through intuitive audio prompts. The system dynamically adapts to environmental changes, ensuring reliable guidance even in complex or crowded spaces. Validation through simulations demonstrates its potential to significantly improve the mobility and independence of users low vision in unfamiliar indoor environments. This work highlights the importance of accessible technology in creating inclusive innovative spaces.

The authors in [26] present an innovative, intelligent evacuation system designed to improve emergency response efficiency in large-scale buildings. The system is user-centric, and dynamic and operates in real-time through a mobile application. It consists of three main components: a positioning system using RFID to detect user locations, a navigation system supported by an Artificial Neural Network (ANN) to provide optimal escape routes based on personal and environmental factors, and a mobile application that offers an intuitive interface with visual and audio guidance for users. Unlike traditional systems that assign static escape routes regardless of user-specific needs, the smart system dynamically adjusts routes in response to changing conditions such as fire growth, visibility, and congestion. It considers personal attributes such as age, health conditions, and familiarity with the building, ensuring tailored evacuation plans. Experimental results demonstrate that the system outperforms traditional methods by reducing risks and adapting to real-time scenarios, highlighting its potential as a safer and more efficient evacuation solution.

The authors in [27] presents an Augmented Reality (AR)-based navigation system designed to assist users in navigating through dark indoor environments. The MARINS system utilizes Apple's ARKit SDK, implementing simultaneous localization and mapping (SLAM) to provide real-time navigation in 0-lux darkness using a smartphone's LED as the sole light source. Key features of MARINS include its real-time environment viewing module, AR guide graphics, and a path-switching module, allowing users to adapt to obstructions dynamically. Tested in a controlled maze environment, MARINS outperformed traditional 2D maps by significantly reducing pathfinding time, travel distance, and misjudgments. Additionally, the system achieved high usability ratings through a comprehensive user satisfaction survey. This study highlights the potential of AR technology for emergency and low-visibility navigation scenarios, emphasizing MARINS' effectiveness as a tool for enhancing safety in challenging conditions.

The authors in [28] introduce a novel localization framework to enhance indoor positioning accuracy. The proposed Smart Indoors Localization Scheme (SILS) utilizes cooperative smartphone networks, combining Bluetooth, WiFi, and GNSS technologies to provide a hybrid and dynamic localization solution. By leveraging smartphones' onboard capabilities and cooperative data exchange among devices, the system achieves reliable positioning in environments where traditional GNSS signals are degraded or unavailable.SILS dynamically adapts to the availability and quality of signals from Bluetooth, WiFi, and GNSS, optimizing accuracy and maintaining robust performance. The framework's design ensures minimal infrastructure requirements, relying instead on the pervasive nature of smartphone technologies. Experimental evaluations demonstrate its effectiveness in achieving precise localization with reduced computational overhead. This research underscores the potential of cooperative smartphone networks in advancing indoor positioning systems and enabling context-aware applications in bright environments.

The authors in [29] present an innovative approach to monitoring and tracking elderly individuals within indoor environments using smartphones. The system combines Wi-Fi signal-based localization with inertial sensor data (e.g., accelerometers and gyroscopes) available on modern smartphones to provide accurate real-time tracking. This dual approach enhances localization accuracy, compensating for the shortcomings of standalone Wi-Fi or inertial sensors in dynamic and complex indoor spaces. The proposed system focuses on improving elderly care by enabling non-invasive monitoring, which can ensure safety and timely assistance in emergencies. The authors validate the system's performance through experimental analysis, demonstrating its ability to track movements while maintaining computational efficiency accurately. The research highlights the potential of leveraging existing smartphone technologies to develop cost-effective, scalable solutions for elderly tracking and indoor navigation, particularly in healthcare and assisted living scenarios.

The authors in [30] explore a novel approach to enhance indoor and urban localization accuracy by synchronizing WiFi access points with GPS time extracted from smartphones. The proposed method addresses the challenge of WiFi-based localization's dependency on precise timing by introducing GPS-derived time synchronization, ensuring consistent and accurate localization measurements. By leveraging the widespread availability of GPS-enabled smartphones, the system minimizes infrastructure modifications while significantly improving the temporal accuracy of WiFi-based localization techniques. Experimental results validate the effectiveness of the synchronization process in enhancing the accuracy of position estimation in hybrid indoor-outdoor environments. This research demonstrates the potential of integrating GPS time synchronization with WiFi infrastructure to bridge the gap between GPS limitations indoors and WiFi's spatial limitations outdoors, contributing to the advancement of seamless localization solutions.

The authors in [31] focus on enhancing the accuracy of indoor positioning systems by normalizing the Received Signal Strength (RSS) values of Wi-Fi access points. Variations in RSS values due to environmental factors, device orientation, and signal interference often reduce the reliability of Wi-Fi-based localization systems. The authors propose a normalization approach to mitigate these variations, improving the consistency of RSS measurements and, consequently, positioning accuracy. The study integrates the normalized RSS data into a smartphone-based positioning solution, combining Wi-Fi localization with other sensor data, such as accelerometers and gyroscopes, for enhanced results. Experimental evaluations demonstrate significant improvements in accuracy and stability across various indoor scenarios. The research highlights the potential of RSS normalization in addressing everyday challenges in Wi-Fi-based positioning, making it a valuable contribution to developing more reliable and robust indoor navigation systems.

The authors in [32] provide an extensive overview of localization technologies for indoor and outdoor environments within the Internet of Things (IoT) context. The authors analyze various techniques, including Wi-Fi, Bluetooth, GPS, UWB, and hybrid methods, assessing their applicability, strengths, and limitations in IoT-driven scenarios. The review emphasizes the increasing demand for accurate and efficient localization solutions due to the proliferation of IoT applications in smart cities, healthcare, and industry. Key challenges include signal interference, energy efficiency, scalability, and integrating heterogeneous technologies. The paper also discusses emerging trends such as machine learning-based localization, fusion of multiple sensor data, and adopting 5G for enhanced accuracy. By outlining unresolved issues and suggesting future research directions, this review is a valuable resource for researchers and practitioners aiming to advance the localization field in the IoT era.

In the context of Assisted GPS (A-GPS) [33], [34]. In the context of mobile phone networks, the technology known as Assisted GPS (A-GPS) is frequently implemented to enhance GPS. The cellular network in A-GPS systems provides informative data to help the GPS receiver calculate an accurate position more quickly. Utilizing data from various sources, A-GPS calculates the position of devices. Traditional GPS cannot detect significantly attenuated signals due to its design, although A-GPS can rectify this issue. Nevertheless, the implementation cost may impede the practical deployment of this system. Furthermore, there are a few drawbacks to A-GPS. Typically, an assistance server requires a subscription to a specific mobile phone plan and frequently incurs additional expenses. Numerous A-GPS devices predominantly rely on the external server; as a result, they may need help operating independently or have a standalone option. This violates privacy, as a third-party server knows your exact location. Furthermore, there are privacy concerns.

The transformative potential of integrating multisensory Metaverse applications with 6G technology is analyzed in [35], focusing on transforming commerce and education through enhanced digital experiences. The article investigates the technical architecture and the function of 6G networks in providing critical ultra-high bandwidth, low latency, and reliability for these applications. It endeavors to analyze and overcome current obstacles in multisensory Metaverse environments by utilizing 6G-enabled edge AI architectures. Practical implementations are illustrated through real-world case studies. The paper also emphasizes the significance of fostering inclusivity and equity in accessing these immersive environments, guaranteeing that technological advancements benefit all users, irrespective of their socioeconomic status or geographical location. This paper outlines its limitations. Initially, the technological complexity of integrating various advanced technologies, such as holographic communication, AI, and high-speed wireless networks, presents substantial obstacles to the demand for seamless interoperability and coordination. The digital divide may also be further exacerbated by unequal access to these cutting-edge technologies, which could disadvantage underserved communities and developing regions. Accessing multisensory Metaverse-6G systems fairly and comprehensively remains a substantial challenge.

The problem gap between the proposed methodology in the paper and the related work is indoor navigation systems' flexible and scalable character. Most indoor navigation solutions presently available are designed to fit specific structures, which requires significant re-development and customization for each new implementation. The high cost of implementation and the absence of flexibility render widespread adoption challenging. Additionally, conventional systems rely heavily on technologies such as GPS, which could be more precise in interior environments due to environmental interferences and non-line-of-sight issues.

The ESINS_AR methodology proposes remedying these deficiencies through augmented reality and visual markers. ESINS_AR provides an adaptable and scalable solution that can be easily integrated into diverse interior environments without requiring extensive redevelopment. This methodology reduces implementation expenses and promotes code reuse. ESINS_AR is a more cost-effective and practical alternative to current indoor navigation solutions. It enhances user interaction through augmented reality and provides accurate, real-time navigation assistance through widely available devices.

III. PRELIMINARIES

Some preliminary steps for developing the proposed navigation system based on augmented reality are detailed in this section.

A. AUGMENTED REALITY (AR)

AR integrates 2D or 3D digital components in real time with the user's physical environment [36]. A device with a camera, sensors, and a display panel, such as a smartphone, tablet, or wearable device, is typical for AR. The device utilizes its camera to capture the real-world scene and processes the video input in real-time, identifying objects, surfaces, and markers. Additionally, it aligns virtual content with the physical environment by overlapping it onto the real-world view.

Plenty of formats in which virtual content can be presented in AR, such as 3D objects, images, videos, text, or interactive elements. Users may acquire additional information, context, or entertainment from these virtual components. For example, in an AR gaming application, virtual characters or objects can be projected onto the physical environment, enabling users to interact with them as if they were a part of the real world. By creating interactive and seamless experiences, augmented reality can bridge the gap between the digital and physical domains. It enables users to engage with virtual content in their real-world environment for an enhanced experience.

B. ARCORE AND SLAM TECHNOLOGY

Augmented reality (AR) experiences are developed using Google's ARCore [37] platform. Integrating virtual content with the actual world through the device's camera enables developers to build AR applications for Android and iOS devices. ARCore uses SLAM (Simultaneous Localization and Mapping) technology [38] to create augmented reality experiences. SLAM is a crucial technique that enables ARCore to understand and interact with the natural world, as illustrated in Figure 2.

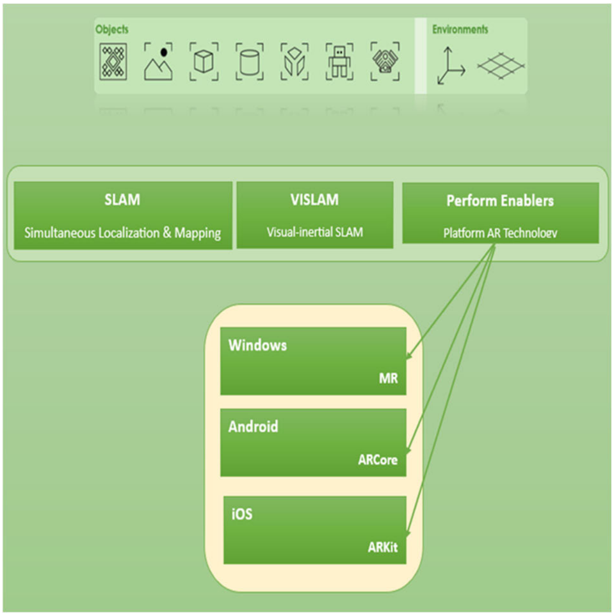

FIGURE 2. The architecture of the SLAM-based AR framework.

Here's a comprehensive look at how ARCore utilizes SLAM technology:

1) WHAT IS SLAM?

Simultaneous Localization and Mapping (SLAM) is a process where a device constructs a map of an unknown environment while keeping track of its location. This is crucial for applications like AR, where the device needs to understand its surroundings and position accurately to place virtual objects correctly.

2) HOW ARCORE USES SLAM

- **Motion Tracking:**

ARCore leverages SLAM to track the device's movement in the real world. It combines visual data from the camera with Inertial Measurement Unit (IMU) sensor data to continuously update the device's position and orientation. By mapping the environment and understanding its location within that space, ARCore can accurately anchor virtual objects to specific points in the real world.

- **Environmental Understanding:**

SLAM enables ARCore to detect and map flat surfaces, such as floors, tables, and walls.

This mapping allows virtual objects to be placed on these surfaces, ensuring they appear stable and correctly positioned.

- **Anchors and Hit Testing:**

Using SLAM, ARCore can create anchors that fix virtual objects to specific points in the environment, ensuring they remain in place even as the device moves. Additionally, SLAM enables ARCore to perform hit testing by casting a ray from the device's camera to detect real-world surfaces, helping to determine where to place virtual objects accurately.

- **Light Estimation:**

ARCore uses SLAM to understand the lighting conditions of the environment. By analyzing the real world, ARCore can adjust the lighting of virtual objects to match, enhancing their realism. Objects reflect the real-world environment based on the illumination of the surroundings.

ARCore facilitates the development of AR applications by offering a robust SDK that integrates seamlessly with popular development platforms like Unity, Unreal Engine, and Android Studio. It supports anchor management, hit testing, and plane detection, allowing developers to create interactive and stable AR experiences. For instance, hit testing projects a ray from the camera view to detect real-world surfaces where virtual objects can be placed. In addition, ARCore's SLAM technology ensures that AR elements remain fixed in place, even as the user moves around. The platform also supports augmented images, enabling applications to recognize and interact with predefined pictures in the environment. ARCore's versatility and ease of integration make it an ideal choice for creating applications like ESINS_AR, where accurate environmental mapping and real-time feedback are critical for user experience.

C. OMNIDIRECTIONAL QR CODES

The QR Code is omnidirectional and can be detected in any direction. Position detection patterns (Finder Patterns) are embedded in the QR Codes, which assist the scanner in determining the appropriate orientation for the image. Numerous small and medium-sized enterprises implement QR Codes for various purposes, including managing payments, executing actionable and trackable print media marketing campaigns, facilitating a more efficient inventory tracking process, and creating interactive event invitation cards.

D. GRID-BASED PATHFINDING IN AR APPLICATIONS

Grid-based systems are a common approach for pathfinding in AR applications. They divide the AR environment into a cell grid representing a specific area or region. These grids serve as a navigational map that can be used to plan paths and guide characters or objects through the AR space.

E. A* SEARCHING ALGORITHM

A* (A-star) [39] search algorithm is a widely used pathfinding and graph traversal technique in various disciplines, such as artificial intelligence, robotics, and computer games. It is intended to minimize the total cost of the path while efficiently determining the shortest path from a start node to a target node. Using a cost function that balances the known path cost and an estimate of the remaining cost, the algorithm incorporates elements of Dijkstra's algorithm and greedy best-first search. Compared to other search algorithms, this hybrid approach enables A* to effectively identify the optimal path by exploring fewer nodes.

A* performs by maintaining a priority queue of nodes to be examined, which are prioritized according to their total estimated cost. The total cost of a node is calculated as the sum of two components: the g-cost, which represents the cost from the start node to the current node, and a heuristic estimate of the h-cost, which means the cost from the current node to the destination node. The heuristic function is designed to estimate the distance to the objective and must be admissible, meaning it should never exceed the actual cost. Nodes are expanded from the queue in order of their total estimated cost, with the path with the lowest overall cost examined first.

In applications that necessitate efficient pathfinding, such as robotics, geographic information systems, and video game navigation systems, A* is extensively employed. The efficiency of the search process is derived from its capacity to concentrate on plausible paths while avoiding less likely routes. In A*, the heuristic function can be customized to address specific issues, enabling optimization and flexibility following the application's requirements. It is a valuable tool in numerous practical pathfinding and optimization problems due to its capacity to ensure the shortest path with a suitable heuristic, even though A* is not always the fastest algorithm in every scenario. A* can be highly efficient, as it reduces the search space by focusing on promising paths. However, in dense grids or complex environments with many obstacles, A* may still explore many nodes, leading to higher computational overhead.

Although Theta* can generate smoother pathways, it typically necessitates a more significant computational burden than A*. Theta* is more resource-intensive, particularly in environments with complex geometries or numerous obstacles, due to the additional computations required for line-of-sight tests between nodes. The increased computational complexity may result in Theta* being slower than A* in specific scenarios.

The A* algorithm establishes the evaluation function, searches from the starting point, selects the node with the minimum total generation value as the next extension node and halts the search until the endpoint, thereby completing the search for the optimal path. In (1), the cost function is represented.

$$f(n) = g(n) + h(n) \tag{1}$$

where $f(n)$ = total estimated cost of path through node n, $g(n)$ = cost so far to reach node n, $h(n)$ = estimated cost from n to goal. This is the heuristic part of the cost function. The Euclidean distance is chosen as the h(n) cost function in this research, and its calculation formula is shown in (2).

$$h(n) = [(x_n - x_m)^2 + (y_n - y_m)^2]^{0.5} \tag{2}$$

where (x_n, y_n) denotes the coordinates of the current path node, and (x_m, y_m) de-notes the coordinates of the target node. The flowchart of the A* algorithm in the actual path search procedure is illustrated in Figure 3.

Traditional A* algorithms are limited to identifying a single optimal path from the beginning to the end by initially dividing the surrounding search space into measurable nodes. The open list and the closed list are generated by the A* algorithm during execution. In the open list, unexpanded nodes are stored, while expanded nodes are stored in the closed list. A node inserted into the Open list is immediately appended to the end, irrespective of its value.

The sizes of all the nodes in the Open list during each expansion are compared. The node with the smallest value is obtained, and the node with the smallest value is withdrawn from the Open list and added to the Close list. Add these nodes to the Open list if they are not already there. Select the minor node as the current node and continue searching for the remaining nodes. The current node will be the parent node if these extended nodes are in the Open list. The cost function will be employed to evaluate the value, which will be recalculated. The steps above will be repeated until the target is located. Finally, the nodes in the Open list will be arranged in reverse order to determine the optimal path.

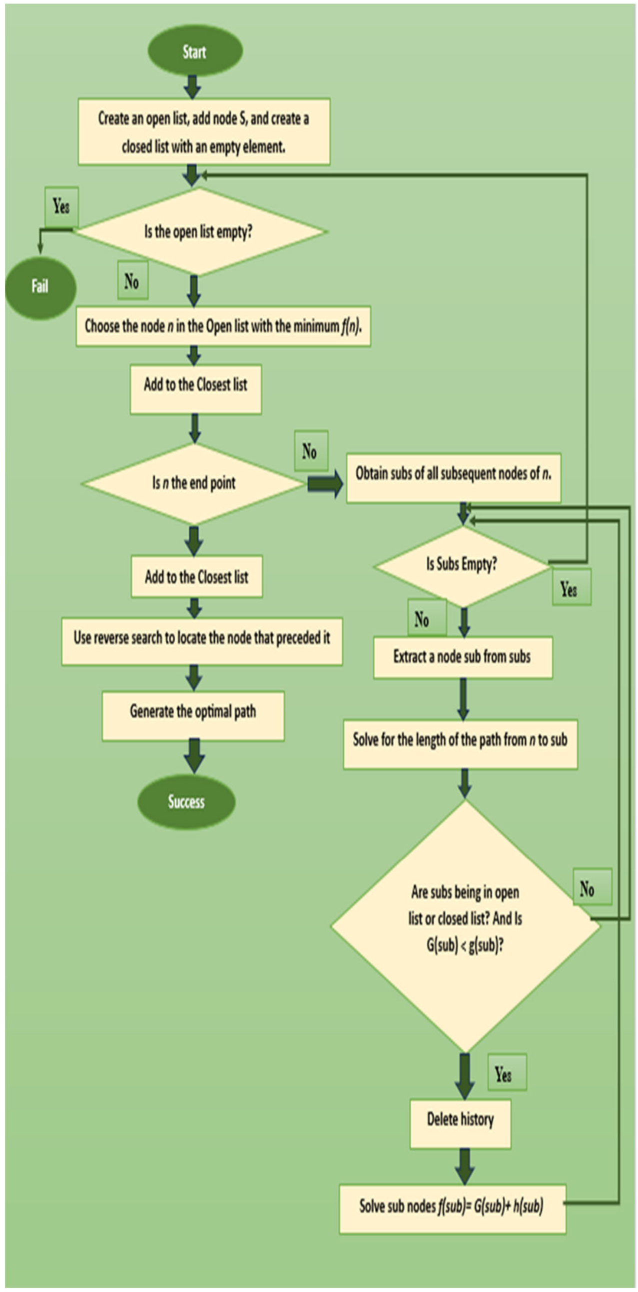

FIGURE 3. Algorithm flowchart.

F. ENHANCEMENT OF A* ALGORITHM

The rasterized map is examined to identify critical nodes to initiate the proposed method. Next, it establishes the target vector *SG*, which indicates the connection line from the current node S to the target point *G*. Following this, the method selects the key node *N* situated in the Manhattan distance around SG and is closest to the target point *G*.

The method deploys an incremental expansion of the A* algorithm and an enhanced cost function to search for a path from *S* to *N* that circumvents obstacles if obstacle nodes are present in the search area of *N*. This process is repeated iteratively, selecting key nodes *N* until *N* corresponds to the target point G, thereby concluding the path planning phase. Figure 4 provides a visual representation of the comprehensive procedure.

IV. SYSTEM DESIGN

System design and analysis comprehend the system components of the proposed ESINS_AR by dismantling the system into its constituent parts. This process is crucial for identifying the system's requirements and constraints. The system design will demonstrate the principal aspects of the proposed system and the system architecture. The proposed system section analyzes the interactions between components and the environment.

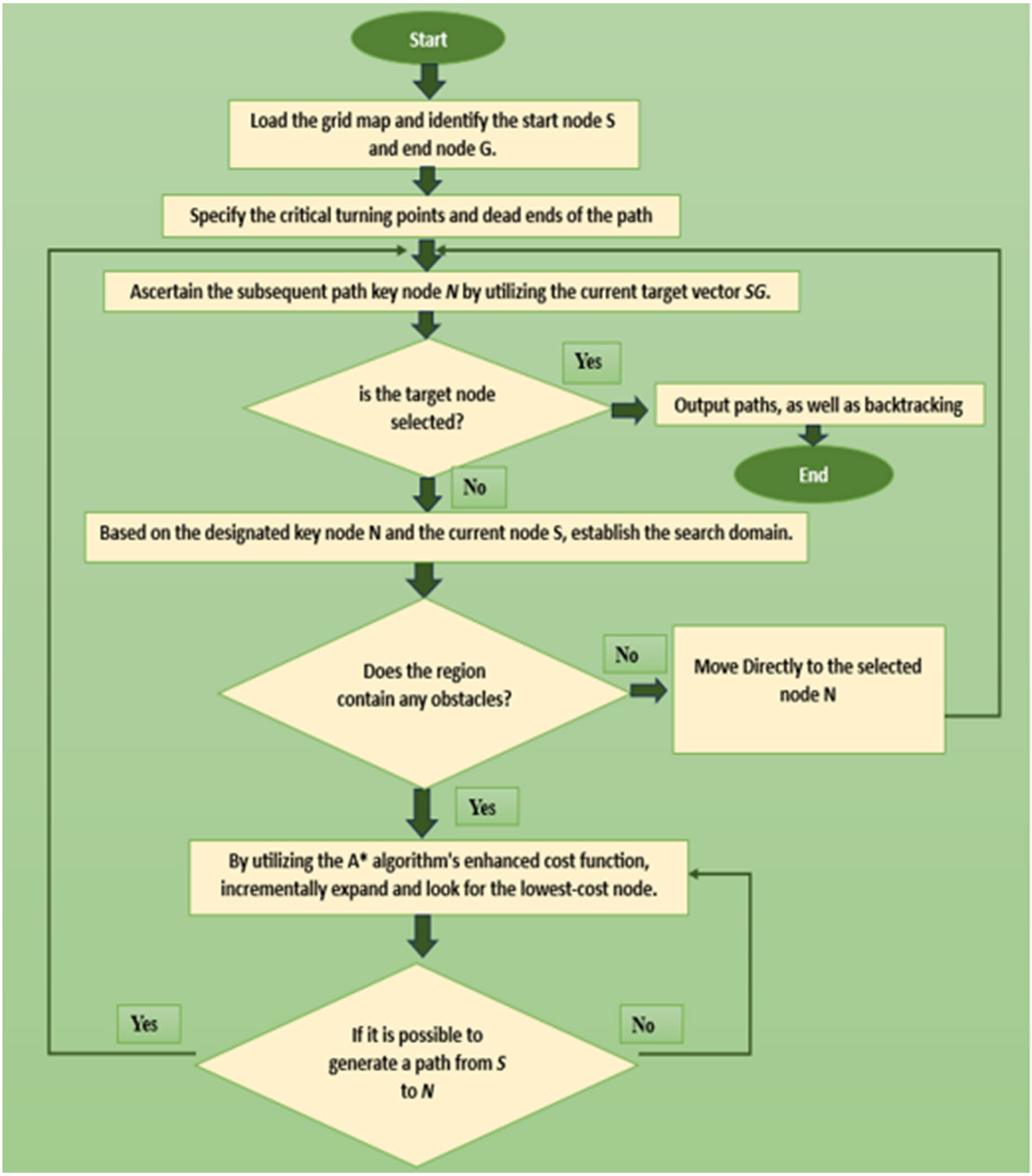

FIGURE 4. Path planning algorithm.

A. SYSTEMS ARCHITECTURE

All components collaborate to deliver location-based information and seamless navigation in indoor environments, as illustrated in Figure 5, which depicts the system architecture of ESINS_AR. Running on smartphones or tablets, the mobile application functions as the user interface, overlaying AR elements onto the real-world view using the device's camera and sensors. Utilizing algorithms such as A*, the environment is represented by a grid-based system that partitions the space into navigable cells, thereby empowering path planning and navigation.

The application for real-time location updates captures the encoded information, and users scan QR codes to ascertain their location. The AR overlay offers interactive elements and visual navigation instructions through visual cues, waypoints, and turn-by-turn directions, improving the user experience by providing clear, intuitive guidance. In addition, the system is designed to provide a seamless and immersive indoor

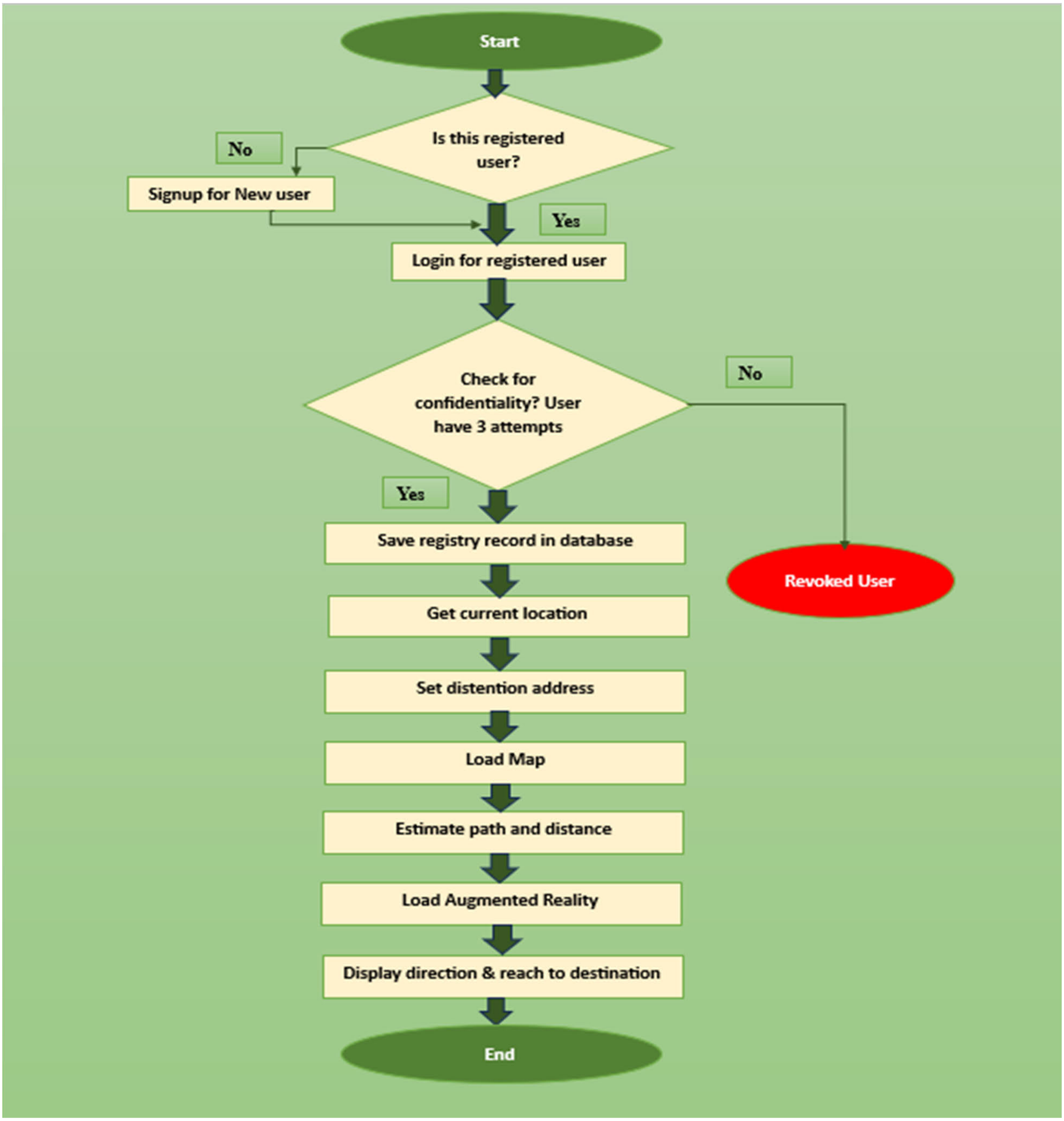

FIGURE 5. System architecture.

navigation experience by integrating with location-based services to provide real-time updates on nearby amenities, points of interest, and contextual information. Six components comprise the proposed systems: mobile application, grid-based system, QR code scanning, augmented reality overlay, path planning and navigation, user interface and instructions, and location-based services. The critical elements of the proposed system are summarized as follows:

1) GRID-BASED SYSTEM

The indoor environment is structured using a grid-based system. A navigational map is created by dividing the environment into a grid of cells. Occupancy values are designated to each cell to indicate whether it is occupied by an obstacle or available for navigation. Each cell represents a distinct area or region. The grid-based system facilitates path planning and navigation within the interior space.

2) MOBILE APPLICATION AND USER INTERFACE

The mobile application provides the user interface for the internal navigation system. It functioned on smartphones or tablets, displayed the navigation interface, interacted with the user, and provided an AR experience. The application overlays AR elements onto the real-world view by integrating with the camera and sensors. The mobile application features a user-friendly interface that offers straightforward and intuitive navigation instructions. This encompasses visual cues, waypoints, turn-by-turn directions, and distance estimations to assist the user in following the intended route. The navigation experience is improved by the AR overlay and graphical user interface (GUI) elements.

3) SCANNING PROCESS USING QR CODE

Integrating QR codes within the ESINS_AR framework is a critical component for enhancing navigation and interaction in augmented reality. Each QR code is specifically generated using Python's QR code library and is designed to encode essential spatial information that allows the system to identify user locations accurately. During operation, the application utilizes a real-time camera feed to scan for these QR codes, employing OpenCV to process the captured images. Upon detection, the QR code data is decoded to retrieve the associated coordinates and relevant metadata, facilitating precise alignment of virtual overlays in the AR environment. The integration process, including the configuration for camera calibration and QR code recognition thresholds, is explicitly described in the methods section with accompanying code snippets, ensuring that other researchers can effectively replicate our approach in various settings.

While QR codes are easy to implement and provide a straightforward solution for indoor navigation, they introduce several limitations. First, a complete set of QR codes must be generated and maintained for each building or space, which can be labor-intensive and challenging, especially in large or frequently changing environments. Second, relying on QR codes for navigation may not be ideal in unique use cases such as building evacuations, where speed and efficiency are paramount, and constant scanning may slow movement. These limitations highlight the need for further research and the development of alternative solutions for such contexts.

4) AR OVERLAY

AR technology is applied by mobile applications to superimpose digital information, including navigation instructions, waypoints, and interactive elements, onto the live camera view of the physical environment. The AR overlay visually indicates the direction to follow or displays relevant data about the user's current location to guide the user.

AR overlay mechanism used in ESINS_AR leverages a sophisticated combination of real-time computer vision algorithms and graphics rendering techniques to provide an interactive user experience. The system begins by utilizing a camera feed to detect predefined markers, such as QR codes, which serve as reference points for virtual content placement. Upon detection, the AR framework we used, Unity, processes the marker's spatial information to accurately position and align the virtual overlays within the physical environment. This involves applying transformation matrices that account for camera perspective and marker orientation. The graphical elements, rendered through OpenGL, are then dynamically adjusted based on the user's viewpoint, ensuring a seamless integration of digital and real-world components. Comprehensive code snippets and configurations for calibration, marker tracking, and overlay rendering are detailed in the methods section, enabling reproducibility for future implementations.

5) PATH FINDING AND NAVIGATION

The grid-based system assists in the efficient planning and navigation of paths. Utilizing algorithms such as A*, D* Lite, or Theta*, the mobile application can determine the most efficient route from the user's current location to the desired destination. The grid-based system and occupancy values are employed to identify obstacles and devise a secure path for the user.

6) LOCATION-BASED SERVICES (LBS)

Integrating the indoor navigation system with LBS can provide additional features and information. This may encompass contextual information regarding specific areas or rooms, indoor maps, floor plans, adjacent amenities, or real-time updates on points of interest (POIs) [21].

An indoor navigation system that combines AR, a grid-based system, and QR codes provides an interactive and immersive navigation experience. This system allows users to easily navigate indoor spaces, locate points of interest, and access pertinent information in real time.

B. PROPOSED SYSTEM ARCHITECTURE

The proposed algorithm for the following algorithm describes the Enhanced Smart Indoor Navigation System Based on Augmented Reality (ESINS_AR) scheme.

The ESINS_AR System algorithm is an extensively used method for determining the shortest path in a graph, and it is an implementation of the A search algorithm*. The A* algorithm is distinguished by its ability to integrate the advantages of the Greedy Best-First search, which employs a heuristic to estimate the remaining distance to the objective, and Dijkstra's algorithm, which concentrates on the actual cost of reaching a node. The outcome is a balance that enables the efficient pathfinding of numerous applications, including robotics, game development, and navigation systems.

A* is significantly influenced by the heuristic function, denoted as h(node). The cost from a specific node to the objective is estimated. The Euclidean distance, which is the straight-line distance between the node and the objective, is the foundation of the heuristic in this implementation. This heuristic assists the algorithm in prioritizing nodes that are situated close to the objective.

The cost function determines the actual cost of migrating from one node to another, denoted as cost(node1, node2). Typically, this is determined by the distance between the two nodes, which may be a physical distance in space or another metric, depending on the graph's context. The ESINS_AR algorithm balances the shortest actual and closest estimated paths by integrating the heuristic estimate with the exact cost.

Algorithm 1 Proposed ESINS_AR System

```
procedure Main()
  g(start) ← 0                  // Cost from start to start is 0
  parent(start) ← NULL          // Start node has no parent
  open ← PriorityQueue()        // The open set (nodes to be evaluated)
  open.Insert(start, g(start) + h(start)) // Insert start node with f = g + h
  closed ← Set()                // The closed set (nodes already evaluated)
  While open is not empty, do // Continue while there are nodes to evaluate
    current ← open.Pop()        // Get the node with the lowest f value

    if current = goal then      // If we reached the goal
      return ReconstructPath(current)
      // Return the path by reconstructing it

closed.Add(current)    // Add the current node to the closed set

    for each neighbor in successors(current) do
      If the neighbor is in closed, then
        continue  // Ignore the neighbor if it's already evaluated

      tentative_gScore ← g(current) + cost(current, neighbor)
      // Calculate tentative g score

      if the neighbor is not in open, then    // Discover a new node
        open.Insert(neighbor, tentative_gScore + h(neighbor))
      else if tentative_gScore >= g(neighbor) then
        continue              // Not a better path

      parent(neighbor) ← current
      // This path is the best until now; record it

      g(neighbor) ← tentative_gScore      // Update g score
      open.Update(neighbor, g(neighbor) + h(neighbor))
      // Update the f value in the open set

return 'No path found'     // If we exhaust the search, no path is found

procedure ReconstructPath(current)
  path ← empty list
  while current is not NULL, do       path.prepend(current)          // Add
current node to the path
    current ← parent(current)       // Move to parent node
  return path                       // Return the reconstructed path

function h(node)
  // Heuristic function estimating the cost from the node to the goal
  return EuclideanDistance(node, goal)

function cost(node1, node2)
  // Actual cost from node1 to node2 (usually the distance between them)
  return EuclideanDistance(node1, node2)

function successors(node)
  // Retrieve neighbors of the current node in the graph
  return list_of_neighbors
```

The successor function returns the neighboring nodes of a specified node, *successors(node)*. These nodes are directly accessible from the current node in the graph. This function is essential for expanding the search, as it determines the potential next steps from each node.

The ESINS_AR algorithm commences by initializing several vital structures. The initial cost of the start node is zero, as there is no expense associated with reaching the starting point from its location. Furthermore, the start node is the path's origin, so it lacks a parent. The ESINS_AR algorithm employs two primary sets: the open set, which is a priority queue that contains nodes that are yet to be evaluated, and the closed set, which includes nodes that have already been assessed and will not be revisited. Based on the sum of the actual cost (g) and the heuristic estimate *(h)*, the start node is included in the open set with a priority. This algorithm extracts the node from the open set with the lowest total cost at each stage, as determined in (3).

$$f = g + h \tag{3}$$

The ESINS_AR algorithm reconstructs the path by tracing back from the goal to the start using parent pointers if this node is the goal. It then returns the path. The current node is included in the closed set to indicate that it has been evaluated and to prevent further consideration if it is not the objective. The algorithm investigates the neighbors of each node, which are supplied by the *successors(current)* function. It is disregarded if a neighbor has already been evaluated and incorporated into the closed set. Alternatively, the algorithm calculates the provisional g-score for that neighbor, which denotes the cost of contacting the neighbor from the beginning through the current node. If the neighbor still needs to be identified (i.e., it is not included in the open set), it is incorporated into the open set. The algorithm determines whether the newly computed putative neighbor has been identified if it has already been identified.

If the g-score is superior to the previously known score, the algorithm updates the neighbor's parent to the current node and modifies its cost in the open set accordingly. This phase guarantees that the algorithm consistently monitors the shortest path to each node it encounters.

The ESINS_AR algorithm exploits the parent pointers to trace back from the goal to the start when the goal node is achieved by invoking the *ReconstructPath(current)* procedure. This generates the algorithm's shortest path. The path is returned as a list of nodes that spans from the start to the objective. The algorithm concludes that no path exists between the start and goal if the open set is exhausted without reaching the objective, and it returns the message *"No path found."* This may occur when the graph is disconnected, or the purpose must be attainable from the outset.

This section provides a comprehensive description of the proposed ESINS_AR scheme. The use case diagram illustrated in Figure 6 elucidates the components and their interactions within the system. Table 1 lists the notations of the proposed ESINS_AR algorithm. A use case is a scenario-based model or specific scenario that outlines the optimal use of a system or process to accomplish a particular objective. The system's end-user utilizes the mobile application for navigation and exploration.

The mobile application provides the primary interface for accessing and employing the indoor navigation system installed on the user's device. Conversely, there are specific interactions between processes, such as the following:

- *The first process* is QR code scanning. In this process, the user interacts with the mobile application to scan QR codes in the interior environment. This interaction assists in determining the user's location or retrieving specific information associated with the QR code.

- *The second process* is viewing an AR overlay. The mobile application employs augmented reality technology to overlay digital information onto the real-world view, which is the process of witnessing an AR overlay. This feature provides additional context-specific data, navigation instructions, and real-time visual cues.
- *The third process* is navigation within the indoor environment; to navigate within the indoor environment, the user employs the mobile application's navigation functionality in the primary procedure of Navigate Indoors here. This entails the establishment of a destination, the receipt of turn-by-turn directions, and the execution of the recommended route.
- *The fourth process* is QR code recognition and placement. In this process, QR codes are affixed to specific locations within the indoor environment, and the system is configured to identify and associate them with pertinent information, such as room identification or location coordinates.
- *The fifth process* is the AR overlay system. The AR Overlay System concentrates on the augmented reality overlay system integrated into the mobile application. This encompasses the rendering and presenting virtual elements, such as navigation indicators, waypoints, or contextual information, onto the live camera view of the real-world environment.
- *The final process* is navigation and path planning. This process includes the algorithms and functionalities responsible for determining the most efficient paths within the interior environment. It considers the user's current location, desired destination, and any obstacles in the grid-based system. The A* algorithm is implemented in the proposed ESINS_AR scheme.

A* is more straightforward to implement than Theta* because it doesn't require additional logic for handling line-of-sight checks or complex parent-node updates. A* follows the grid connections, which makes the algorithm more straightforward and less error-prone. A* guarantees finding the shortest path in a grid environment, assuming the heuristic is admissible (does not overestimate the cost) and consistent. This is important in applications requiring exact, guaranteed path optimality within the grid structure. Since A* explores fewer paths and doesn't check for line-of-sight connections between non-adjacent nodes, it often requires less memory. It keeps track of fewer potential paths, especially in large, complex grids with many obstacles. A* is particularly well-suited for applications where the environment is highly discrete or represented as a grid (such as tile-based games, 2D maps, or graph-like structures). In such environments, grid-aligned movement (which A* enforces) may be desirable or even required.

A*'s node-to-node movement in grid-based systems is more predictable and more manageable to control. This can benefit applications like turn-based games or simulations where discrete movement aligns better with the system's mechanics. In environments where movement is highly constrained (e.g., maze-like grids or narrow passages between obstacles), A* may perform better. It systematically explores every possible path, ensuring no paths are missed, which can be beneficial when precise movement along a grid is critical.

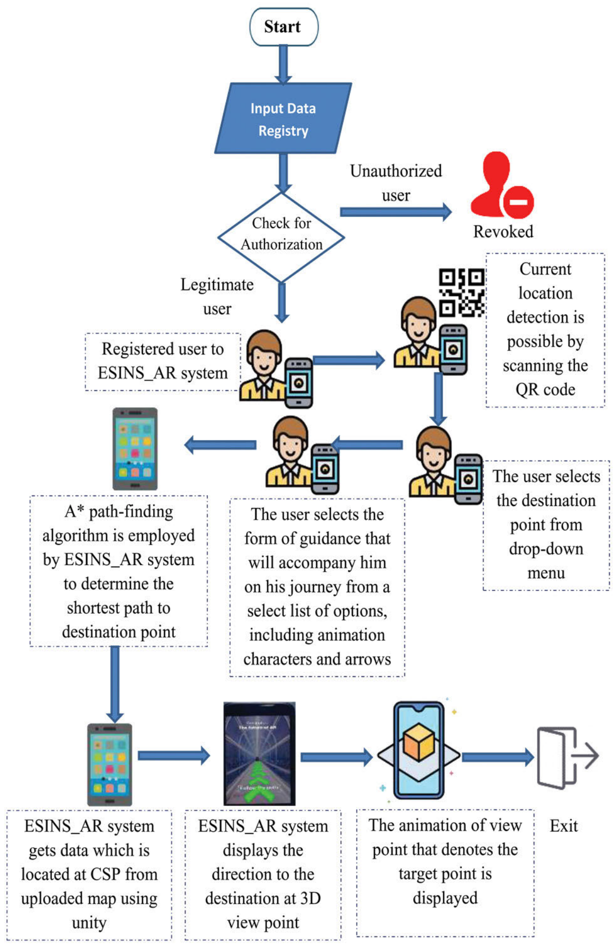

FIGURE 6. Proposed ESINS_AR system.

V. SYSTEM EVALUATION METHODOLOGICAL ADVANCEMENTS IN THE UPDATED VERSION

The methodology in the Updated Version (ESINS_AR) introduces significant advancements over the Main Manuscript (SINS_AR) [5], addressing limitations and expanding upon the original system's capabilities. These enhancements are detailed as follows:

A. PATHFINDING ALGORITHM

The Main Manuscript relies on the Theta* algorithm, which optimizes navigation by creating smoother and more natural paths. However, this approach comes with increased computational complexity and higher memory demands, especially in dynamic environments with frequent changes. In contrast,

TABLE 1. List of notations.

Symbol	Quantity
g(node)	The actual cost to reach the node from the start.
h(node)	The heuristic estimate of the cost to reach the goal from the node.
f(node)	The total estimated cost of the path through the node.
parent(node)	Tracks the parent of each node, i.e., the node from which it was reached.
successors(node)	The neighboring nodes of the given node in the graph.
tentative_gScore	The tentative cost of reaching a neighbor through the current node.
cost(node1, node2)	estimated distance from the initial position to the final destination position. A heuristic function to calculate the estimated value is used.
start	The starting node of the pathfinding algorithm.
goal	The target node the algorithm is trying to reach.
open	A priority queue (open set) of nodes to be evaluated.
closed	A set of nodes that have already been evaluated.
current	The node is currently being evaluated.

the Updated Version adopts the A* algorithm, a computationally efficient alternative that balances accuracy and resource utilization. The A* algorithm prioritizes paths based on a cost function, ensuring reliability in both static and dynamic scenarios while reducing overhead on resource-constrained devices such as smartphones.

B. SCALABILITY

A significant limitation in the Main Manuscript is the system's reliance on building-specific customization, necessitating extensive redevelopment for each new application. The Updated Version resolves this issue by introducing a modular architecture that supports seamless adaptability across various indoor settings. This design promotes code reusability and minimizes both development time and cost, enabling the system to scale efficiently to diverse environments.

C. AUGMENTED REALITY (AR) INTEGRATION

The Main Manuscript employs basic AR overlays with static visual markers, which lack dynamic interaction with the surrounding environment. The Updated Version enhances this functionality by integrating SLAM (Simultaneous Localization and Mapping) technology, enabling real-time mapping and dynamic AR overlays. This improvement provides users with immersive, context-aware navigation, as visual guidance is accurately superimposed on the physical environment, further enriched by real-time lighting adjustments and spatial anchoring.

D. MOBILE APPLICATION FEATURES

The original application in the Main Manuscript provides basic functionality, focusing on location detection and static directional guidance. The Updated Version introduces dynamic QR-based localization, allowing users to scan QR codes for precise positioning. The application also supports real-time destination updates and enhanced interactivity, significantly improving usability and adaptability to various contexts, such as shopping malls, hospitals, and universities.

E. GRID-BASED NAVIGATION SYSTEM

While the grid-based system is not explicitly detailed in the Main Manuscript, the Updated Version formalizes its implementation. The indoor environment is divided into a structured grid, where each cell indicates navigability or obstacles. This approach facilitates accurate path planning and efficient obstacle avoidance, providing a foundation for reliable navigation in complex environments.

F. EVALUATION AND METRICS

The Main Manuscript limits its evaluation to feasibility checks, lacking robust performance metrics. The Updated Version conducts comprehensive evaluations, including accuracy, response time, runtime, and user satisfaction metrics. Comparative analyses with other systems further highlight the enhanced performance and real-world applicability of ESINS_AR, validating its superiority across multiple dimensions.

G. COST EFFICIENCY

Customization in the Main Manuscript incurs high costs due to the need for redevelopment in new environments. The Updated Version emphasizes cost-efficiency through modularity and widely available resources such as smartphones and QR codes. This approach reduces implementation costs while maintaining system flexibility, making it a practical choice for organizations with limited budgets.

H. REAL-WORLD APPLICATION

The Main Manuscript demonstrates its application in limited environments, such as lecture halls and shopping malls. In contrast, the Updated Version expands validation to include a wider range of settings, such as hospitals, government buildings, and large transit hubs. These tests underscore the system's robustness and adaptability, proving its effectiveness in diverse and complex indoor environments.

The following table summarizes the differences between the two versions:

VI. SYSTEM EVALUATION

This section will assess the ESINS_AR scheme's efficacy from both the user and administrator perspectives.

A. TOOLS AND SIMULATION PROCESS

The subsequent list of process steps is the following:

1) PREPARING THE MAP

The initial phase of the proposed ESINS_AR software involves the creation of a 2D map of the building model.

TABLE 2. Comparison of methodological enhancements between main manuscript (SINS_AR) and updated version (ESINS_AR).

Aspect	Main Manuscript (SINS_AR)	Updated Version (ESINS_AR)	Expansion Details
Pathfinding Algorithm	Utilizes Theta* for smoother paths but with high complexity.	Implements A* algorithm for efficiency and accuracy in pathfinding.	Improved computational performance and scalability in handling dynamic environments.
Scalability	Limited to specific buildings, requiring redevelopment.	Adaptable across diverse structures with minimal redevelopment.	Significant focus on code reusability and reduced implementation costs.
AR Integration	Basic AR with visual markers for guidance.	Advanced AR overlays with SLAM for real-time navigation.	Enhanced immersive experience through dynamic real-world mapping and interaction.
Mobile App Features	Basic navigation within predefined environments.	Includes QR-based localization, real-time updates, and flexibility.	Expanded user interaction and feature set for ease of navigation and adaptability.
Grid-Based System	Not explicitly detailed.	Introduces a detailed grid-based system for navigation.	Enables precise navigation, obstacle handling, and path planning.
Evaluation Metrics	Limited to feasibility checks.	Comprehensive evaluation, including accuracy, runtime, and response.	Offers thorough comparative analyses with existing systems for validation.
Cost Efficiency	Customization incurs high costs for new implementations.	Reduces costs through modularity and use of existing resources.	Achieves cost savings via flexibility and reduced redevelopment efforts.
Real-World Application	Validated in limited scenarios like malls and universities.	Broader validation in various complex environments.	Demonstrates robustness and applicability in diverse, large-scale settings.

Subsequently, the ESINS_AR software executes various processes on the 3D model map. To construct the 3D model from the 2D representation, Revit [40] is utilized. Revit employs parametric modeling techniques, whereby modifications to one model component automatically refresh associated elements and views. The 3D map was imported into Unity by ESINS_AR, which then unpacked all of the 3D objects in the model. The purpose of the ESINS_AR software is to enhance the application's efficacy. To achieve this, it is necessary to reduce the size of the 3D map by removing any extra elements, including the ceiling, doors, and interior staircases in the halls. These elements are not advantageous for indoor navigation, and ESINS_AR eliminates them to reduce the map's size accordingly. Then, in the navigation application, walls should not appear to prevent confusing the user, so ESINS_AR creates a material in Unity to make the walls transparent and apply it over all the walls.

2) APPLYING THE NAVIGATION TOOLS

Unity includes a feature known as NavMesh, which is an acronym for "Navigation Mesh." This feature is primarily based on the A* path-finding algorithm. Figure 7 illustrates the map after applying both NavMesh and the A* algorithm.

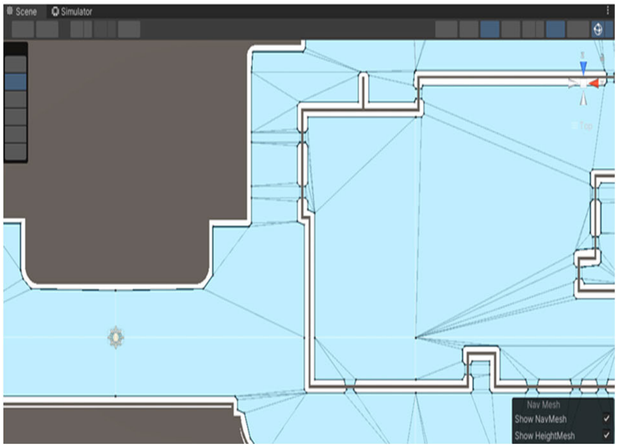

FIGURE 7. The 3D map after applying NavMesh and A* algorithm.

3) ESTABLISHING THE TARGETS ON THE MAP

To ascertain the potential destinations for the user to select from, ESINS_AR must establish a group of target cubes in front of the destinations. The proposed system presumes room numbers are named and chosen from the menu.

4) CREATING THE LINE RENDERING

The Line Renderer is a component that enables the rendering of lines or arcs in a game scene. This utility is beneficial for visualizing paths, trajectories, or any other line-based elements in your game. The line rendering is implemented to generate a line that will guide the user.

5) REPOSITIONING THROUGH QR CODE TECHNOLOGIES

By positioning QR codes at strategic locations within an environment where they can be scanned with their mobile devices, users can effortlessly reposition the start point to their current position and recalculate the shortest path from their current positions to their desired target points.

The mobile application in ESINS_AR primarily utilizes QR codes for initial location detection. When a user scans a QR code, the application captures the encoded information, which includes the user's current location. This serves as the starting point for navigation.

The application employs a combination of technologies to track the user's movement after the initial location, including the device's built-in sensors (such as accelerometers and gyroscopes) and AR capabilities. These sensors help detect changes in the user's position and orientation as they move through the indoor environment. Based on this sensor data, the application continuously updates the user's location, allowing it to adjust the navigation arrows and provide real-time guidance.

While the QR codes are essential for establishing the user's starting point, they do not need to be scanned repeatedly as the user moves. Instead, the application maintains an ongoing understanding of the user's location through sensor data. However, if the user moves to a significantly different area or if the application loses track of the user's position (for example, due to environmental factors), it may prompt the user to scan a QR code again to recalibrate their location.

B. METRIC OF EVALUATING PERFORMANCE

A technical performance assessment was implemented to assess the technology's efficacy and feasibility. The following terms are metrics that serve as the primary scale for comparing the schemes: SINS_AR [5], RF_PR [8], A-GPS [23], [24], and the proposed ESINS_AR scheme.

In the case of SINS_AR, we chose to utilize the A* algorithm instead of the Theta* algorithm for pathfinding. A* provides a more effective heuristic approach, facilitating quicker and more accurate route optimization in dynamic environments. This choice improves performance metrics and addresses specific limitations of Theta*, particularly in scenarios with complex obstacles and varying terrain.

Moreover, in RF_PR, integrating the A* algorithm enhances positioning capabilities compared to traditional RFID methods. A* significantly improves real-time adaptability and accuracy in navigation, boosting ESINS_AR's overall effectiveness. Additionally, we opted for the A* algorithm in place of A_GPS. This shift allows for more precise navigation in environments where GPS signals may be unreliable or unavailable, thus enhancing the robustness of our approach in indoor contexts.

The application's feasibility is assessed by evaluating its capacity to detect the walking pace. The following subsection covers the accuracy, processing time, and response time.

1) RESPONDING TIME

The response time is the time between the conclusion of the query request and the initiation of the response. Figure 8 illustrates the simulation of architectures for varying request rates (20, 50, 150, and 300 requests per second).

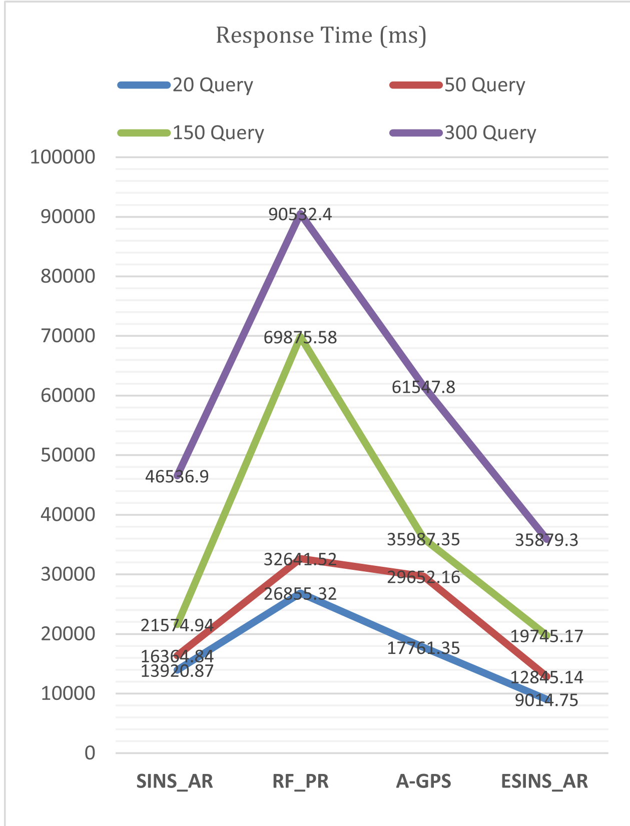

FIGURE 8. The response time comparison.

The response time of all schemes increases swiftly as the number of requests per second increases. Nevertheless, the ESINS_AR algorithm achieves the shortest response time. Among the others, ESINS_AR is the most reliable. SINS_AR is implemented to provide theta* methods that are inaccessible during runtime. It is not optimal to have increased computational complexity, particularly in dynamic or obstacle-dense environments, and potential challenges in correctly handling non-walkable zones within a NavMesh structure, as the responding time exceeds SINS_AR due to its high implementation complexity.

2) RUNTIME EVALUATION

The schemes were evaluated by comparing the obstacle density of each map under consideration and the time required to plot the path from a random start node to a destination node on the desired map. Figure 9 illustrates the time required for each scheme to detect the path on a 100 × 100 map.

100 × 100 map refers to a grid-based system in which the indoor environment is divided into 10,000 individual grid cells, each representing a navigable area within the space. While the cells can be uniform in size, the specific dimensions may vary depending on the layout and requirements of the indoor environment being modeled.

The runtimes of each scheme to determine the path from a given start node to the destination node based on varying

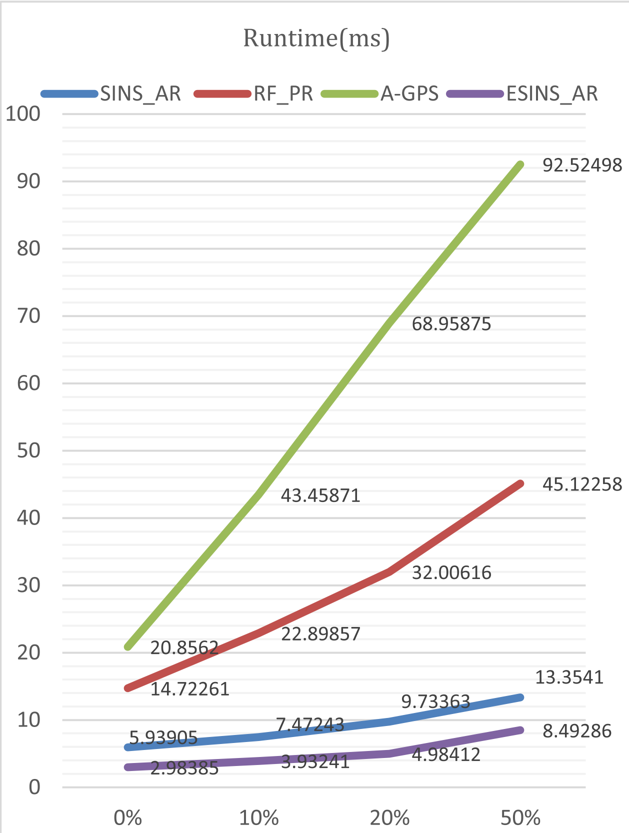

FIGURE 9. Runtime of each scheme to plot the paths on a 100 × 100 user-designed map.

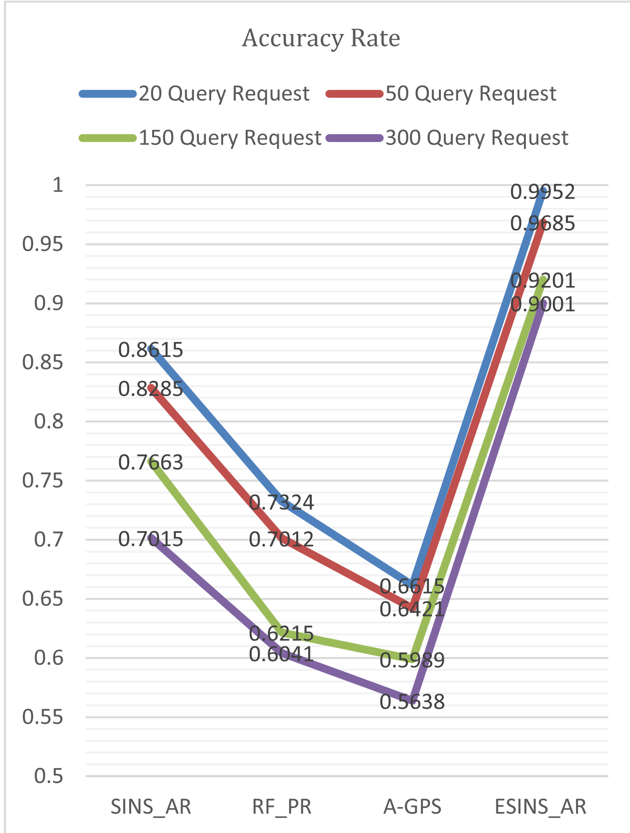

FIGURE 10. Rate of accuracy in the comparison of the proposed system with state-of-the-art algorithms.

obstacle densities are as follows: ESINS_AR takes the least amount of time to find the path to the objective, followed by SINS_AR, RF_PR, and A-GPS. The unpacked procedure of removing all unnecessary objects to reduce the size of the map resulted in the least amount of Runtime at ESINS_AR. The A-GPS scheme has the highest runtime since all barriers are obstacles. RF_PR follows the A-GPS scheme because it provides UHF-RFID, which is incompatible with use in environments that evolve metal or water, as these items can disrupt its signal. Therefore, water or metal are classified as obstacles.

3) RATING OF ACCURACY

The accuracy rate can be calculated by dividing the number of requested queries by the number of valid response queries as formed in (4).

$$AccuracyRate = \frac{\text{Total Number of Requested Queries}}{\text{Number of Valid Response Queries}} \tag{4}$$

Therefore, the most optimal performance is achieved when the accuracy rate value equals or nearly 1. The most severe scenario is the occurrence of 300 query requests simultaneously, which results in the formation of a bottleneck. Figure 10 illustrates the findings.

During the bottleneck of the most significant query request numbers, the performance of ESINS_AR is reduced to an estimated 5%, which is regarded as a negligible and acceptable deviation. The accuracy rate of the proposed ESINS_AR scheme value can consistently exceed 95% when using variant request numbers. The accuracy can reach approximately 100% in the best-case scenario, which involves only 20 requests.

When referring to "300 queries," we mean 300 simultaneous requests for pathfinding from various start points to their respective goals. This scenario simulates a high-demand environment, allowing us to evaluate the system's performance under stress. Significantly, this approach does not detract from the overall efficacy of ESINS_AR; it demonstrates the system's robustness and ability to handle multiple requests efficiently, as evidenced by our results showing an accuracy rate consistently exceeding 95%. This performance indicates that ESINS_AR is well-equipped to provide reliable navigation assistance in real-world applications.

VII. CONCLUSION

This paper presents a solution to GPS issues that occur in confined environments. The accuracy and efficacy of indoor navigation solutions can be improved by the proposed Smart Indoor Navigation System Using Augmented Reality, ESINS_AR. In ESINS_AR, the user should be able to navigate an unfamiliar interior setting using an innovative smartphone that scans a QR code to detect their position and select their desired destination, with the assistance of direction arrows that are augmented in the real world and visible through smartphones. A* pathfinding is employed by the proposed ESINS_AR scheme to determine the shortest path to the destination. A genuine traffic scenario at an indoor colossal building in Egypt, with varying node densities, was considered to facilitate the analysis of Indoor Navigation performance metrics. The following metrics are included: accuracy rate, response time, runtime analysis, and path length analysis. The application that uses Revit, Unity, Visual Editor, and C# to support Unity scripting, Cross-Platform Development, and a physics engine that enables developers to create realistic interactions between objects in the game world has been used and evaluated to implement the scenario. The ESINS_AR scheme was determined to be the most reliable of the extant schemes due to its minimal response time, as demonstrated by the analysis. Furthermore, ESINS_AR obtains the highest accuracy rate and requires the least time to determine the path to the destination node. Modifying the line-of-sight checks, ESINS_AR optimizes any-angle algorithms to eliminate unnecessary turns in free space and reduce the time required to locate the path. The ongoing and forthcoming work is concentrated on implementing security mechanisms to protect privacy when transmitting queries to cloud providers.

While the current implementation of the ESINS_AR system focuses on simplifying navigation by excluding vertical elements such as interior staircases, future iterations will address comprehensive multi-level navigation. Incorporating these elements can provide a seamless experience for users navigating buildings with multiple floors. We plan to explore advanced algorithms and visualization techniques that balance clarity with functionality, ensuring users receive accurate and context-aware guidance across all dimensions. Additionally, integrating features for accessibility, such as routes optimized for users with mobility constraints, will further broaden the system's usability and inclusivity.

Future work will also focus on leveraging Building Information Modeling (BIM). BIM provides a sustainable and standardized solution for almost all buildings, offering a detailed representation of structural and functional aspects. Integrating BIM into future iterations of the ESINS_AR system could enhance scalability and applicability by enabling seamless adaptation across diverse environments while improving sustainability and efficiency.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this paper, where Diaa Salama Abdelminaam and Ahmed Elsayed Mansour participated in sorting the experiments, discussed and analyzed the results, and revised/edited the manuscript. Ala Saleh Alluhaidan performed the experiments, analyzed the results, and wrote the article. Yasmin Alkady discussed the results and wrote the article. Yasmin Alkady and Diaa Salama Abdelminaam discussed the results and revised the article. All authors read and approved the work in this article.

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REFERENCES

[1] M. S. Ramesh, J. Naveena Ramesh Vardhini, S. Murugan, and J. Albert Mayan, "Indoor navigation using augmented reality for mobile application," in *Proc. 7th Int. Conf. Intell. Comput. Control Syst. (ICICCS)*, Madurai, India, May 2023, pp. 1049–1052, doi: 10.1109/ICICCS56967.2023.10142362.

[2] S. H. Alsamhi, A. V. Shvetsov, A. Hawbani, S. V. Shvetsova, S. Kumar, and L. Zhao, "Survey on federated learning enabling indoor navigation for industry 4.0 in B5G," *Future Gener. Comput. Syst.*, vol. 148, pp. 250–265, Nov. 2023.

[3] L. Qi, Y. Liu, Y. Yu, L. Chen, and R. Chen, "Current status and future trends of meter-level indoor positioning technology: A review," *Remote Sens.*, vol. 16, no. 2, p. 398, Jan. 2024, doi: 10.3390/rs16020398.

[4] T. Liu, J. Liu, J. Wang, H. Zhang, B. Zhang, Y. Ma, M. Sun, Z. Lv, and G. Xu, "Pseudolites to support location services in smart cities: Review and prospects," *Smart Cities*, vol. 6, no. 4, pp. 2081–2105, Aug. 2023, doi: 10.3390/smartcities6040096.

[5] Y. Alkady, R. Rizk, D. M. Alsekait, A. S. Alluhaidan, and D. S. Abdelminaam, "SINS_AR: An efficient smart indoor navigation system based on augmented reality," *IEEE Access*, vol. 12, pp. 109171–109183, 2024, doi: 10.1109/ACCESS.2024.3439357.

[6] E. B. Aydogan and Y. Atay, "Unity based a algorithm used in shortest path finding problem for helicopters," in *Proc. Int. Conf. Control, Autom. Diagnosis (ICCAD)*, Nov. 2021, pp. 1–5.

[7] J.-R. Jiang and H. Subakti, "An indoor location-based augmented reality framework," *Sensors*, vol. 23, no. 3, p. 1370, Jan. 2023.

[8] F. Bernardini, A. Buffi, D. Fontanelli, D. Macii, V. Magnago, M. Marracci, A. Motroni, P. Nepa, and B. Tellini, "Robot-based indoor positioning of UHF-RFID tags: The SAR method with multiple trajectories," *IEEE Trans. Instrum. Meas.*, vol. 70, pp. 1–15, 2021.

[9] F. Endres, J. Hess, J. Sturm, D. Cremers, and W. Burgard, "3-D mapping with an RGB-D camera," *IEEE Trans. Robot.*, vol. 30, no. 1, pp. 177–187, Feb. 2014.

[10] F. Kallasi, D. L. Rizzini, and S. Caselli, "Fast keypoint features from laser scanner for robot localization and mapping," *IEEE Robot. Autom. Lett.*, vol. 1, no. 1, pp. 176–183, Jan. 2016.

[11] R. Gutierrez-Osuna, J. A. Janet, and R. C. Luo, "Modeling of ultrasonic range sensors for localization of autonomous mobile robots," *IEEE Trans. Ind. Electron.*, vol. 45, no. 4, pp. 654–662, Aug. 1998.

[12] L. Zhang and H. Wang, "3D-WiFi: 3D localization with commodity WiFi," *IEEE Sensors J.*, vol. 19, no. 13, pp. 5141–5152, Jul. 2019.

[13] P. Barsocchi, A. Crivello, M. Girolami, F. Mavilia, and F. Palumbo, "Occupancy detection by multi-power Bluetooth low energy beaconing," in *Proc. Int. Conf. Indoor Positioning Indoor Navigat. (IPIN)*, Sep. 2017, pp. 1–6.

[14] A. Cazzorla, G. De Angelis, A. Moschitta, M. Dionigi, F. Alimenti, and P. Carbone, "A 5.6-GHz UWB position measurement system," *IEEE Trans. Instrum. Meas.*, vol. 62, no. 3, pp. 675–683, Mar. 2013.

[15] V. Pasku, A. De Angelis, G. De Angelis, A. Moschitta, and P. Carbone, "Magnetic field analysis for 3-D positioning applications," *IEEE Trans. Instrum. Meas.*, vol. 66, no. 5, pp. 935–943, May 2017.

[16] W. Lv, Y. Kang, and J. Qin, "Indoor localization for skid-steering mobile robot by fusing encoder, gyroscope, and magnetometer," *IEEE Trans. Syst., Man, Cybern., Syst.*, vol. 49, no. 6, pp. 1241–1253, Jun. 2019.

[17] R. Rizk and Y. Alkady, "Two-phase hybrid cryptography algorithm for wireless sensor networks," *J. Electr. Syst. Inf. Technol.*, vol. 2, no. 3, pp. 296–313, Dec. 2015.

[18] C. Li, L. Mo, and D. Zhang, "Review on UHF RFID localization methods," *IEEE J. Radio Freq. Identificat.*, vol. 3, no. 4, pp. 205–215, Dec. 2019.

[19] J. Lai, C. Luo, J. Wu, J. Li, J. Wang, J. Chen, G. Feng, and H. Song, "TagSort: Accurate relative localization exploring RFID phase spectrum matching for Internet of Things," *IEEE Internet Things J.*, vol. 7, no. 1, pp. 389–399, Jan. 2020.

[20] T. Hasler, M. Wölbitsch, M. Goller, and S. Walk, "Relative tag locations based on time-differences in read events for practical applications," *IEEE J. Radio Freq. Identificat.*, vol. 4, no. 1, pp. 55–64, Mar. 2020.

[21] P. V. Nikitin, R. Martinez, S. Ramamurthy, H. Leland, G. Spiess, and K. V. S. Rao, "Phase based spatial identification of UHF RFID tags," in *Proc. IEEE Int. Conf. RFID (IEEE RFID)*, Orlando, FL, USA, Apr. 2010, pp. 102–109.

[22] F. Farouk, Y. Alkady, and R. Rizk, "Efficient privacy-preserving scheme for location based services in VANET system," *IEEE Access*, vol. 8, pp. 60101–60116, 2020.

[23] M. Valizadeh, B. Ranjgar, A. Niccolai, H. Hosseini, S. Rezaee, and F. Hakimpour, "Indoor augmented reality (AR) pedestrian navigation for emergency evacuation based on BIM and GIS," *Heliyon*, vol. 10, no. 12, Jun. 2024, Art. no. e32852, doi: 10.1016/j.heliyon.2024.e32852.

[24] Y. Inoue, A. Sashima, T. Ikeda, and K. Kurumatani, "Indoor emergency evacuation service on autonomous navigation system using mobile phone," in *Proc. 2nd Int. Symp. Universal Commun.*, Takamatsu, Japan, Dec. 2008, pp. 79–85, doi: 10.1109/isuc.2008.49.

[25] J. Ahn and R. Han, "RescueMe: An indoor mobile augmented-reality evacuation system by personalized pedometry," in *Proc. IEEE Asia–Pacific Services Comput. Conf.*, Jeju, South Korea, Dec. 2011, pp. 70–77, doi: 10.1109/APSCC.2011.26.

[26] İ. Karas, M. Rahman, J. A. Rahman, and S. Zlatanova, "A 3D, volumetric approach for 3D cadastre: A case study from Turkey," in *Proc. 12th 3D GeoInfo Conf.*, Melbourne, VIC, Australia, Oct. 2017, pp. 1–13. [Online]. Available: https://web.karabuk.edu.tr/ismail.karas/files/4_3D_GeoInfo_2017_Manuscript_21.pdf

[27] P.-H. Diao and N.-J. Shih, "MARINS: A mobile smartphone AR system for pathfinding in a dark environment," *Sensors*, vol. 18, no. 10, p. 3442, Oct. 2018, doi: 10.3390/s18103442.

[28] I. A. Lami, H. S. Maghdid, and T. Kuseler, "SILS: A smart indoors localisation scheme based on on-the-go cooperative smartphones networks using onboard bluetooth, WiFi and GNSS," in *Proc. 27th Int. Tech. Meeting Satell. Division Inst. Navigat.*, Tampa, FL, USA, Sep. 2014, pp. 503–509.

[29] S. A. Maghdid, H. S. Maghdid, and S. Rahman, "Tracking indoor elderly-people using onboard smartphones Wi-Fi device and inertial sensors," in *Proc. 1st Int. Conf. Adv. Res. Eng. Sci. (ARES)*, Baghdad, Iraq, Jun. 2018, pp. 1–8, doi: 10.1109/ARESX.2018.8723267.

[30] I. A. Lami and H. S. Maghdid, "Synchronising WiFi access points with GPS time obtained from smartphones to aid localisation," in *Proc. Int. Conf. Comput. Appl. Technol. (ICCAT)*, Sousse, Tunisia, Jan. 2013, pp. 1–6, doi: 10.1109/ICCAT.2013.6522052.

[31] H. D. Abdulkarim and H. Sarhang, "Normalizing RSS values of Wi-Fi access points to improve an integrated indoors smartphone positioning solutions," in *Proc. Int. Eng. Conf. (IEC)*, Erbil, Iraq, Jun. 2019, pp. 171–176, doi: 10.1109/IEC47844.2019.8950559.

[32] S. M. Asaad and H. S. Maghdid, "A comprehensive review of indoor/outdoor localization solutions in IoT era: Research challenges and future perspectives," *Comput. Netw.*, vol. 212, Jul. 2022, Art. no. 109041, doi: 10.1016/j.comnet.2022.109041.

[33] A. Ya'u Gital, M. Abdulhamid, M. Abdulhameed, F. U. Zambuk, M. Nehemiah, M. A. Lawal, and Z. I. Yakubu, "Review of GPS-GSM based intelligent speed assistance systems: Development and research opportunities," in *Proc. 3rd Int. Conf. Intell. Commun. Comput. Techn. (ICCT)*, Jaipur, India, Jan. 2023, pp. 1–8, doi: 10.1109/ICCT56969.2023.10076115.

[34] R. Li, P. Wu, L. Feng, H. Tong, and Z. Ren, "Assisted-GNSS positioning algorithm based on one-way fuzzy time information," *Heliyon*, vol. 9, no. 9, Sep. 2023, Art. no. e20318, doi: 10.1016/j.heliyon.2023.e20318.

[35] M. H. Alsamh, A. Hawbani, S. Kumar, and S. Hamood Alsamhi, "Multisensory metaverse-6G: A new paradigm of commerce and education," *IEEE Access*, vol. 12, pp. 75657–75677, 2024.

[36] H. Ling, "Augmented reality in reality," *IEEE MultimediaMag.*, vol. 24, no. 3, pp. 10–15, Mar. 2017.

[37] Z. Oufqir, A. El Abderrahmani, and K. Satori, "ARKit and ARCore in serve to augmented reality," in *Proc. Int. Conf. Intell. Syst. Comput. Vis. (ISCV)*, Fez, Morocco, Jun. 2020, pp. 1–7.

[38] W. Chen and Y. Liu, "Research on unmanned system vision SLAM technology," in *Proc. Int. Conf. Big Data, Artif. Intell. Internet Things Eng. (ICBAIE)*, Fuzhou, China, Jun. 2020, pp. 439–442.

[39] K. Ping and L. Shuai, "A brief introduction of an improved a search algorithm," in *Proc. 10th Int. Comput. Conf. Wavelet Act. Media Technol. Inf. Process. (ICCWAMTIP)*, Chengdu, China, Dec. 2013, pp. 146–148.

[40] J. Redmond, "Revit 3D modeling optimizes substation design," in *Proc. IEEE Rural Electric Power Conf. (REPC)*, Savannah, GA, USA, Apr. 2022, pp. 84–87.

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