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RESEARCH ARTICLE

SINS_AR: An Efficient Smart Indoor Navigation System Based on Augmented Reality

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ABSTRACT With the rapid growth of technology in smart city networks, navigation inside complex buildings is difficult to navigate within such structures. Since the indoor Global Positioning System (GPS) works within an ultra-high radio frequency range, thick walls can negatively affect the quality of signals. The lack of GPS signals and line of sight with orbiting satellites makes navigation more challenging than in outdoor environments. Radiofrequency (RF) signals, Assisted GPS, and sensor-based solutions are used for tracking users in indoor environments, but they have some issues. This paper proposes the Smart Indoor Navigation System Using Augmented Reality (SINS_AR). It provides a solution for this challenge using available and accessible resources. It is used to get the best solution for indoor environments. When implementing the proposed system, a shop within a shopping mall, a specific room in a hotel, or a lecture room in a university can be easily located, providing the users with visual assistance that is reasonably accurate through their smartphones to reach the desired location. SINS_AR system is inspired by augmented reality and 2-D Visual markers. Several visual markers are placed in the complex building structure that when scanned using the application, arrows displayed on the screen lead the users to their destination. The application allows the users to choose their desired destination and also allows them to change their destination in between.

INDEX TERMS Assisted GPS, augmented reality, global positioning system, indoor navigation, radiofrequency.

I. INTRODUCTION

The world is focusing on the evolution of smart cities and new techniques that emerge from innovations in information technology, so "Modern problems require modern solutions.". Due to the advance of the Internet of Things (IoT) and business opportunities, indoor navigation systems have been deployed in many large buildings, such as big train stations, shopping malls, hospitals, and government buildings.

An indoor navigation system [1] means tracking the user's position, planning feasible routes, and guiding the user through the paths to reach the target destination. The indoor navigation system is a must nowadays to help people with no prior knowledge of the facility's map navigate within the building without any obstacles; outdoor navigation system

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positioning technologies such as Global Positioning System (GPS) will not be efficient.

The main objective of [2] is to explore and evaluate the potential of Federated Learning (FL) in enabling efficient and privacy-preserving indoor navigation systems for Industry 4.0 within Beyond 5G (B5G) networks, focusing on various applications such as data sharing, localization, navigation, and human activity recognition. There are several limitations of utilizing Federated Learning (FL) for indoor navigation in Industry 4.0 environments. Firstly, FL faces significant privacy and security concerns, particularly with backdoor poisoning attacks and differential privacy leaks during model updates. These vulnerabilities require robust solutions to ensure the security of both user and cloud data. Additionally, managing resources efficiently during FL training on mobile devices poses challenges, as the varying computational capacities of devices can impact the convergence and accuracy of the overall model. Furthermore, the heterogeneity of data and devices in smart manufacturing environments complicates the implementation of FL, necessitating adaptive algorithms to handle diverse data sources. Finally, the integration of FL with existing Industry 4.0 technologies, such as IoT and Big Data, requires new standards and protocols to enable seamless interoperability and effective data processing across various platforms.

In indoor environments, the GPS cannot provide fair accuracy in tracking due to non-line-of-sight issues [3]. This limitation makes implementing GPS in indoor navigation systems more difficult, although solving this problem is possible using "high-sensitivity GPS receivers or GPS pseudolites" [4]. However, the implementation cost can be considered as a significant barrier to the practical application of this system in real-world scenarios. Navigation through indoor areas is more difficult than outdoor areas. The indoor areas contain different types of obstacles, which increases the difficulty of implementing navigation systems.

The increasing complexity of indoor environments, such as large shopping malls, hospitals, and universities, presents significant challenges for navigation. Traditional GPS-based systems fail to provide accurate indoor positioning due to their reliance on signals that cannot penetrate thick walls or maintain a line-of-sight with satellites. Alternative technologies, including RF signals, Assisted GPS, and various sensor-based solutions, either suffer from high costs, environmental interferences, or limited accuracy, making them impractical for widespread adoption.

Moreover, existing indoor navigation systems are often tailored for specific buildings, lacking the flexibility to be easily adapted to different environments. This customization requirement leads to high costs and significant development efforts, as new applications must be built almost from scratch for each new building, contrary to the principle of code reusability.

In response to these issues, this paper introduces the Smart Indoor Navigation System Using Augmented Reality (SINS_AR). SINS_AR leverages augmented reality to provide an intuitive and cost-effective indoor navigation solution. By utilizing visual markers placed strategically within buildings, users can receive real-time navigation assistance through their smartphones. The system overlays digital navigation cues onto the physical environment, guiding users efficiently to their destinations.

This paper proposes the proposed Smart Indoor Navigation System Using Augmented Reality (SINS_AR) based on other positioning technologies. As a step towards the future, we brought the digital world into the hands of the user via "Augmented Reality" presented by bringing digital components as guidance arrows into the real world to achieve the highest levels of facilitating user usage for the navigation application.

SINS_AR helps users determine their target destinations without wasting time searching for the maps' kiosks or asking the people around them for the shortest paths. But the main problem we can find within the existing indoor navigation applications is that they only work for a specific building, as it is customized for only this building. This inflexibility will lead to so much cost and effort when we are trying to apply the same application on different buildings like we are developing the application from scratch instead of just doing some code refactoring or changing the model, which is not achieving the purpose of the technology, which is mainly depends on code reusability we are seeking to obtain within the projects we are working on, to achieve the highest efficiency and the lowest effort and cost of the code.

So, the trending technology of Augmented Reality (AR) using SINS_AR can help users make the navigation feel more interactive and immersive. In SINS_AR, the world becomes the interface as people exercise more intuitive controls. With direction arrows augmented in the real world that are seen via handheld devices such as smartphones, the user will be navigated in an indoor setting that is unfamiliar to him and for which the application has been configured.

The proposed SINS_AR system aims to overcome the limitations of current indoor navigation technologies by offering a flexible, scalable, and user-friendly solution that can be easily implemented across various indoor settings without extensive redevelopment. This approach not only enhances user experience but also reduces the cost and effort associated with deploying indoor navigation systems.

The main contributions of the paper "SINS_AR: An Efficient Smart Indoor Navigation System Based on Augmented Reality" are as follows:

- The paper proposes a novel Smart Indoor Navigation System Using Augmented Reality (SINS_AR) that integrates AR technology with visual markers to provide accurate and interactive indoor navigation assistance.
- Unlike traditional systems that are tailored for specific buildings, SINS_AR offers a flexible and scalable solution. It can be easily adapted to different indoor

environments without significant redevelopment, thus promoting code reusability and reducing implementation costs.

- By utilizing augmented reality, the SINS_AR system enhances user interaction and experience. Users can navigate complex indoor spaces using their smartphones, receiving real-time visual guidance through AR overlays that display direction arrows and navigation cues.
- The use of widely available smartphones and simple visual markers reduces the need for expensive hardware and infrastructure modifications, making SINS_AR a cost-effective alternative to existing indoor navigation solutions.
- The SINS_AR system employs the Theta* pathfinding algorithm, which optimizes route planning by reducing unnecessary turns and providing more direct paths. This results in improved navigation accuracy and efficiency compared to traditional methods.
- The paper includes a thorough performance evaluation of the SINS_AR system, demonstrating its effectiveness in terms of response time, runtime analysis, and accuracy. Comparative analyses with existing technologies highlight the superior performance of SINS_AR in various metrics.
- The proposed system is validated through real-world scenarios, such as navigation within large buildings like universities and shopping malls. This practical application underscores the system's robustness and applicability in diverse environments.
- By integrating augmented reality with indoor navigation, SINS_AR represents a step towards future-oriented technology that bridges the gap between digital and physical realms, providing users with a seamless and interactive navigation experience.

The sections of this paper are arranged as follows: Section II presents the related work. Section III presents the preliminaries. Section IV covers the system architecture and proposed system. Section V shows the performance of the proposed system. Finally, Section VI concludes the work.

II. RELATED WORK

To date, many schemes that tend to indoor navigation systems are presented, but many of them are not completely suitable for accurate indoor navigation systems. In Indoor Navigation System _ Augmented Reality (INS_AU) [5] that used to design and build an augmented reality-based system for indoor navigation applications. INS_AU system is mainly divided into four basic modules: AR Core-based localization, QR code repositioning, Unity NavMesh navigation [6], and AR path showing. This system tries to avoid a lack of precision or accuracy when using an indoor positioning system (IPS) [7] since there is no line of sight for satellites inside buildings. This system uses the NavMesh components to generate a mesh and is helpful for pathfinding inside buildings. The interior navigation system is used to find the destination path from the current user location through enormous buildings. The system will select the shortest path using a star pathfinding algorithm if there are multiple paths. The main drawback in the INS_AU system when using Build NavMesh with the A* method is that it is unavailable at Runtime. Because it is very complex to implement, not optimal when there are multiple targets, and very high memory consumption, finally, it causes a very high time of execution to have the accuracy of heuristics.

In RFID Positioning Robot (RFID_PR) [8] that used for locating people or objects inside buildings. A variety of technological techniques are used to get the assigned localization accuracy and precision as cameras [9], lasers [10], sonars [11], WiFi [12], Bluetooth [13], ultra-wideband [14], magnetic fields [15], encoders and/or inertial sensors [16], [17], and Radio Frequency Identification (RFID) [18]. Passive RFID technology at the ultra-high frequency (UHF) band is used in the RFID_PR system to detect tags and a reading range of up to ten meters.

Moreover, UHF-RFID technology allows deploying tag sorting [19], [20] and tag localization features [21], [22]. UHF-RFID technology tags have been presented when a robot equipped with a reader antenna moves over multiple trajectories, which may not be contiguous in time. UHF-RFID is very powerful, has shorter wavelengths, and is sensitive to interference. This means that scanned items like metal or water can disrupt its signal; however, mechanisms are in place to ensure that all material products can be tracked with UHF technology. There are some drawbacks of this scheme as the wave signal of UHF-RFID is not compatible with the scanned environment evolve metal or water because these items can disrupt its signal; UHF-RFID has frequencies from 300 MHz to 3 GHz so that it reads range up to 12 meters (40 feet) so that it had to use robot to transmit signals through road, in addition to high power consumption for using this robot, inability to use cell phones as scanners, even though there are fixed and remote RFID readers available, using a phone to scan them is not possible, as can be done using barcodes. This is especially limiting as it requires drivers or employees in the field to carry specific RFID readers to do any scans or connect RFID readers to the same robot. Cell phones cannot be a backup if the provided readers fail.

In Assisted GPS (A-GPS) [4], [23]. A common technology enhancing GPS, especially in mobile phone networks area, is Assisted GPS (A-GPS). In A-GPS systems, useful information is provided by the cellular network that can aid the GPS receiver to calculate an accurate position more quickly. A-GPS uses information from several sources during device position calculation. Due to its design, traditional GPS does not have the sensitivity required to detect highly attenuated signals, although A-GPS can solve it. However, the implementation cost can present a barrier to real-world scenarios application of this system. Also, A-GPS has a few downsides, though. An assistance server usually requires a subscription, for instance, to a particular cell phone plan and often costs extra. Many A-GPS devices depend mainly on the outside server, so they may not be able to function without it or have a standalone option. There are also some privacy concerns, as a third-party server thus knows your exact location, which means privacy violation.

In [24], authors explore the transformative potential of integrating multisensory Metaverse applications with 6G technology, focusing on reshaping commerce and education through enhanced digital experiences. The paper investigates the necessary technical architecture and the role of 6G networks in providing the ultra-high bandwidth, low latency, and reliability required for these applications. It aims to analyze and overcome existing challenges in multisensory Metaverse environments using 6G-enabled edge AI architectures, presenting real-world case studies to showcase practical applications. Additionally, the paper emphasizes promoting inclusivity and equity in access to these immersive environments, ensuring that technological advancements benefit all users regardless of their geographical location or socioeconomic status. This paper outlines several limitations. Firstly, the technological complexity of integrating various advanced technologies, such as holographic communication, AI, and high-speed wireless networks, poses significant challenges due to the need for seamless interoperability and coordination. Additionally, there is a risk of exacerbating the digital divide, as access to these cutting-edge technologies may not be equitable, potentially leaving underserved communities and developing regions at a disadvantage. Ensuring broad and fair access to multisensory Metaverse-6G systems remains a critical challenge

The problem gap identified in the related work versus the proposed methodology in the paper revolves around the flexibility and scalability of indoor navigation systems. Existing indoor navigation solutions are often tailored to specific buildings, requiring significant redevelopment and customization for each new implementation. This lack of flexibility and high cost of implementation create a barrier to widespread adoption. Additionally, traditional systems rely heavily on technologies such as GPS, which are not accurate for indoor environments due to non-line-of-sight issues and environmental interferences.

The proposed methodology, the Smart Indoor Navigation System Using Augmented Reality (SINS_AR), aims to address these gaps by leveraging augmented reality and visual markers. SINS_AR provides a flexible and scalable solution that can be easily adapted to various indoor settings without extensive redevelopment. This approach reduces implementation costs and promotes code reusability. By using augmented reality, SINS_AR enhances user interaction and provides accurate, real-time navigation assistance through widely available smartphones, making it a more practical and cost-effective alternative to existing indoor navigation solutions.

III. PRELIMINARIES

This section presents some preliminaries for building the proposed navigation system based on augmented reality.

A. AUGMENTED REALITY

AR integrates 2D or 3D digital components with the user's real world in real time [25]. AR typically requires a device such as a smartphone, tablet, or wearable device with a camera, sensors, and a display screen. The device captures the real-world scene through its camera and then processes the video feed in real time, recognizing objects, surfaces, and markers. It superimposes virtual content onto the real-world view, aligning it with the physical environment.

The virtual content in AR can take various forms, including 3D objects, images, videos, text, or interactive elements. These virtual elements can provide the user with additional information, context, or entertainment. For example, in an AR gaming application, virtual characters or objects can be projected onto the physical surroundings, allowing users to interact with them as if they were part of the real world. Augmented reality can bridge the gap between the digital and physical realms, creating seamless and interactive experiences. It allows users to explore and interact with virtual content in their real-world environment, providing a deeper level of engagement.

B. ARCORE TECHNOLOGY

ARCore [26] is a software development kit (SDK) developed by Google that enables the creation of AR experiences for Android devices. It provides developers with the tools and capabilities to build AR applications that overlay digital content in the real world. ARCore utilizes the device's camera and sensors to understand the environment and track the position and orientation of the device in real-time using Simultaneous Localization and Mapping (SLAM) technology [27] to provide accurate tracking and spatial understanding, which is essential for optimal navigation and interaction in augmented reality experiences. It enables motion tracking, environmental understanding, and light estimation, which is essential for creating AR experiences.

Using the technology of ARCore and the SLAM technology implemented within ARCore will provide us with the navigation assistance we need to move within the building without using the GPS for tracking purposes.

C. POSITION QR CODE

QR Code is omnidirectional and can be viewed/scanned any way around. The QR Codes themselves include position detection patterns (Finder Patterns), which help the scanner identify the correct orientation for the image. Many businesses (small and medium) are using QR Codes, for example, Making and receiving payments, running actionable and trackable print media marketing campaigns, enabling a faster and smoother process for inventory tracking, and making event invitation cards interactive.

D. GRID-BASED SYSTEMS

Grid-based systems are a common approach for pathfinding in AR applications. They involve dividing the AR environment into a cell grid, each 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. THETA* SEARCHING ALGORITHM

Theta* is an optimization of the A* algorithm [28] that aims to improve the efficiency and naturalness of the generated paths by reducing the number of unnecessary turns or zigzag movements. It achieves this by introducing a technique called ''theta pruning'' that allows for more direct paths.

Euclidean Distance Heuristics like A*, Theta* utilize a heuristic function to estimate the cost from a given node to the goal. The Euclidean distance between two points is often used as the heuristic, assuming a straight-line path between them.

Theta* incorporates the concept of ''line of sight'' checks. Instead of strictly adhering to the grid structure of the environment, it allows for diagonal movements if there is a clear line of sight between neighboring cells. This allows for more direct paths and reduces unnecessary turns. The key optimization in Theta* is the ''theta pruning'' technique. During the search process, when expanding a node, Theta* checks for a clear line of sight between the parent node and the successor node. If there is, the successor node can be reached via a more direct path, and unnecessary intermediate nodes can be pruned from the search.

Theta* is well-suited for dynamic environments as it can adapt to changes during pathfinding. It can dynamically refine the path when changes occur by performing additional line-of-sight checks and theta pruning to find a more optimal and direct route.

By allowing diagonal movements and using theta pruning, Theta* tends to generate smoother and more natural paths than A*. Reducing unnecessary turns and zigzag movements can result in more visually pleasing and efficient paths.

Theta* guarantees admissibility, meaning it will always find a valid path if one exists. However, it does not guarantee optimality like A* does. In some cases, due to the line-of-sight checks and theta pruning, Theta* may produce suboptimal paths compared to A*. However, the paths generated are still generally of high quality.

Theta* has a similar computational complexity to A*, with a worst-case time complexity of O(b^d), where b is the branching factor, and d is the depth of the optimal path. The additional line-of-sight checks and theta pruning add some computational overhead, but the overall impact is generally manageable.

IV. SYSTEM DESIGN

System design and analysis is the process of understanding the system components of the proposed SINS_AR. It involves breaking down the system into its components. System design and analysis is an important step to identify the requirements and constraints of the system. System design will illustrate the main points of System Architecture and the proposed System. The examining how components interact with each other and with the environment is presented in the proposed system section.

A. SYSTEMS ARCHITECTURE

All components work together to provide seamless navigation and location-based information within indoor environments, as shown in Figure 1.

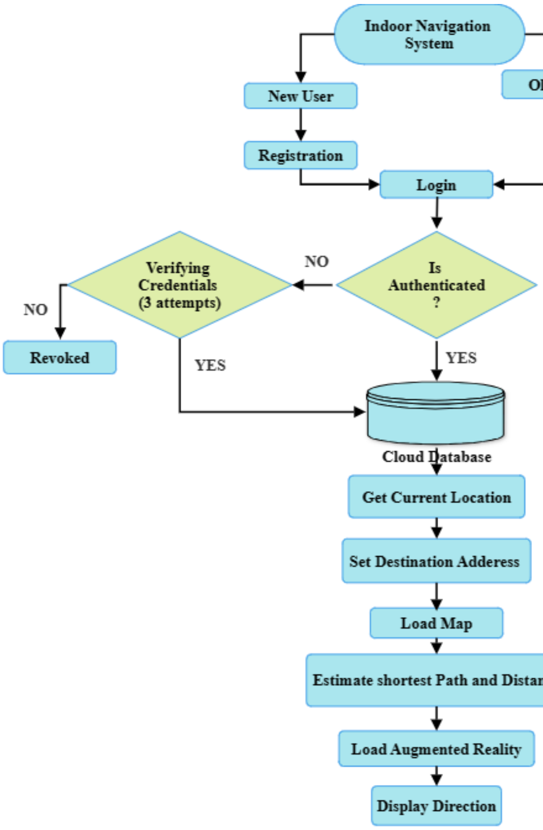


FIGURE 1. System architecture.

Figure 1 illustrates the system architecture of the Smart Indoor Navigation System Using Augmented Reality (SINS_AR). The mobile application serves as the user interface, running on smartphones or tablets, and uses the device's camera and sensors to overlay AR elements onto the real-world view. The environment is represented by a grid-based system that divides the space into navigable cells, facilitating path planning and navigation using algorithms like Theta*. Users scan QR codes to determine their position, with the app capturing encoded information for real-time location updates. The AR overlay provides visual navigation instructions and interactive elements, enhancing user experience with clear, intuitive guidance through visual cues, waypoints, and turn-by-turn directions. Additionally, the system integrates with location-based services to offer real-time updates on points of interest, nearby amenities, and contextual information, ensuring a seamless and immersive indoor navigation experience.the proposed systems consists of seven parts (Mobile Application, Grid-Based System, QR Code Scanning, Augmented Reality Overlay, Path Planning and Navigation, User Interface and Instructions, and Location-Based Services)

The main key components of the proposed system are presented as the following:

1) MOBILE APPLICATION

The mobile application serves as the user interface for the indoor navigation system. It runs on smartphones or tablets, provides the AR experience, displays the navigation interface, and interacts with the user. The application integrates with the camera and sensors to overlay AR elements onto the real-world view.

2) GRID-BASED SYSTEM

A grid-based system is employed to represent the indoor environment in a structured manner. The environment is divided into a grid of cells, forming a navigational map. Each cell represents a specific area or region, and occupancy values are assigned to indicate whether a cell is occupied by an obstacle or free for navigation. The grid-based system facilitates path planning and navigation within the indoor space.

3) QR CODE SCANNING

The mobile application utilizes the device's camera to scan and decode the QR codes in real time. When a user scans a QR code, the application captures the encoded information, such as the location or identifier associated with the QR code. This information is used to determine the user's current position or to provide context-specific information related to that location.

4) AUGMENTED REALITY OVERLAY

Using AR technology, the mobile application overlays digital information, such as navigation instructions, waypoints, or interactive elements, onto the live camera view of the physical environment. The AR overlay guides the user by visually indicating the direction to follow or displaying relevant information about the user's current location.

5) PATH PLANNING AND NAVIGATION

The grid-based system enables efficient path planning and navigation. Using algorithms like A*, D* Lite, or Theta*, the mobile application can calculate the optimal path from the user's current location to the desired destination. The grid-based system and occupancy values help identify obstacles and plan a safe route for the user.

6) USER INTERFACE AND INSTRUCTIONS

The mobile application presents a user-friendly interface that provides clear and intuitive instructions for navigation. This includes visual cues, waypoints, turn-by-turn directions, and distance estimations to guide the user along the planned path. The AR overlay and graphical user interface (GUI) elements enhance the navigation experience.

7) LOCATION-BASED SERVICES

The indoor navigation system can integrate with location-based services to provide additional features and information. This may include real-time updates on points of interest (POIs) [21], nearby amenities, indoor maps, floor plans, or contextual information related to specific areas or rooms.

By combining these components, an indoor navigation system using AR, a grid-based system, and QR codes offers an interactive and immersive navigation experience, enabling users to navigate indoor spaces with ease, locate points of interest, and access relevant information in real time.

B. PROPOSED SYSTEM

The proposed algorthith for In this section, the proposed Smart Indoor Navigation System Based on Augmented Reality SINS_AR scheme is described in the following algorithm.

The proposed SINS_AR system utilizes a combination of augmented reality and the Theta* algorithm to provide efficient indoor navigation. The system begins by initializing components and loading a grid-based map of the environment. Users scan QR codes to set their initial position, and the mobile application captures real-time camera feeds to overlay AR navigation elements onto the real-world view. The Theta* algorithm calculates the optimal path to the destination, and the system updates navigation instructions and waypoints dynamically. If the user scans a new QR code or changes their destination, the path is recalculated. The system continuously provides intuitive AR-based guidance, ensuring accurate and user-friendly indoor navigation.

In this section, the proposed SINS_AR scheme is described in detail. Use case diagram illustrates the explanation of the components and their interactions in the system. A use case is a specific scenario or scenario-based model that describes how a system or process should be used to achieve a particular goal. In software development, a use case describes a specific interaction between the expected users and a system that results in a specific outcome, as shown in Figure 2.

The system's end-user interacts with the mobile application for navigation and exploration. The mobile application is installed on the user's device, providing the primary interface for accessing and utilizing the indoor navigation system. On the other hand, there are some interactions between components as the following:

Algorithm 1 Proposed SINS_AR System

```
procedure Main()
   $g(s\_start) \leftarrow 0$
   $parent(s\_start) \leftarrow s\_start$
   open ← empty priority queue
   open.Insert(s_start, $g(s\_start) + h(s\_start)$)
   closed ← empty set
   while open is not empty do
      $s \leftarrow$ open.Pop()
      if $s == s\_goal$ then
         return ‘Path found’
      $closed \leftarrow closed \cup \{s\}$
      for each $s' \in successors(s)$ do
         if s’ not in closed then
            if s’ not in open then
               $g(s') \leftarrow \infty$
               $parent(s') \leftarrow$ NULL
            UpdateVertex(s, s’)
      return ‘No path found’
   procedure UpdateVertex(s, s’)
      if LineOfSight(parent(s), s’) then
         if $g(parent(s)) + c(parent(s), s') < g(s')$ then
            $parent(s') \leftarrow parent(s)$
            $g(s') \leftarrow g(parent(s)) + c(parent(s), s')$
      else
         if $g(s) + c(s, s') < g(s')$ then
            $parent(s') \leftarrow s$
            $g(s') \leftarrow g(s) + c(s, s')$
   function LineOfSight(s1, s2)
      // Checks if there is a clear line of sight between s1 and s2
   function h(s)
      // Heuristic function estimating the cost from s to the goal
```

1) SCANNING QR CODES

The process of scanning QR Codes that the user interacts with the mobile application to scan QR codes placed within the indoor environment. This interaction helps determine the user’s location or retrieves specific information related to that QR code.

2) VIEWING AR OVERLAY

The process of viewing AR overlay is that the mobile application overlays digital information onto the real-world view using augmented reality technology. This feature provides real-time visual cues, navigation instructions, and additional context-specific data.

3) NAVIGATION WITHIN INDOOR ENVIRONMENT

The main process of Navigate Indoors Her the user utilizes the mobile application’s navigation functionality to navigate within the indoor environment. This involves setting a destination, receiving turn-by-turn directions, and following the suggested path.

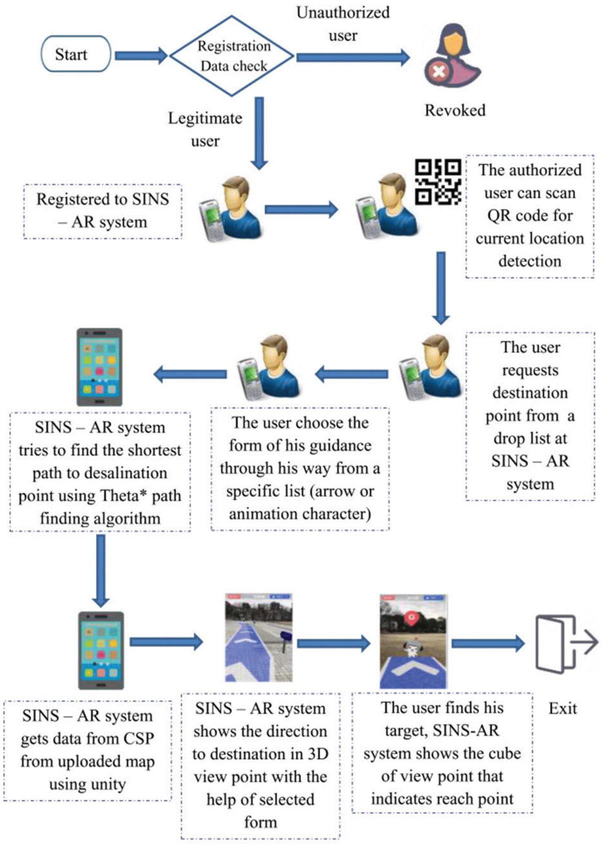


FIGURE 2. Proposed SINS_AR system.

4) QR CODE PLACEMENT & RECOGNITION

This process involves placing QR codes at specific locations within the indoor environment and configuring the system to recognize and associate them with relevant information, such as room identification or location coordinates.

5) AR OVERLAY SYSTEM

AR Overlay System focuses on the augmented reality overlay system within the mobile application. It includes the rendering and displaying of virtual elements, such as navigation arrows, waypoints, or contextual information, onto the live camera view of the real-world environment, as shown in Figure 3 and Figure 4.

6) NAVIGATION AND PATH PLANNING

This process encompasses the algorithms and functionalities responsible for calculating optimal paths within the indoor environment. It considers the user’s current location, desired destination, and obstacles in the grid-based system. Proposed SINS_AR scheme uses Theta* algorithm instead of using A* algorithm.

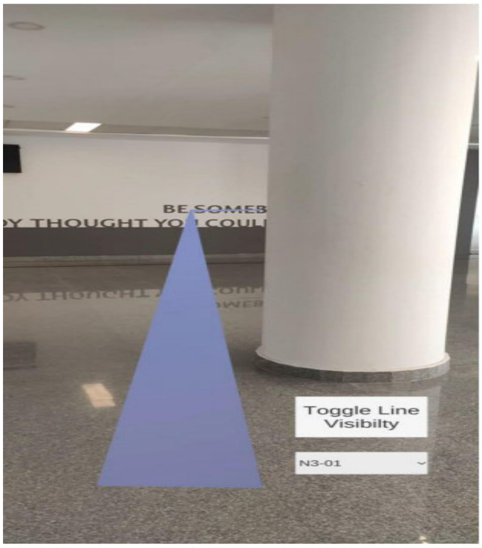


FIGURE 3. Choosing the destination.

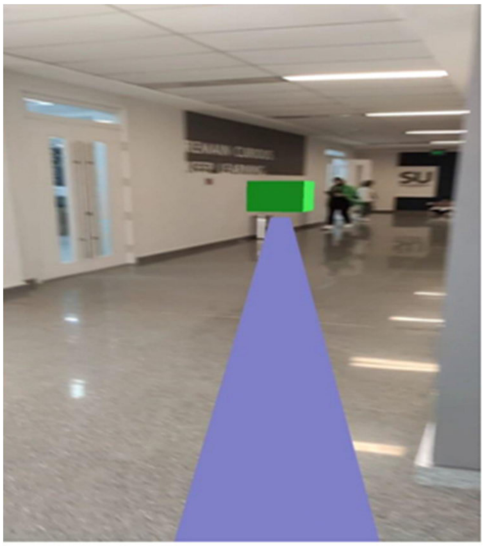


FIGURE 4. Reaching the target cube.

TABLE 1. List of notations.

Symbol	Quantity
S	set of all grid vertices
s_{start}	start vertex of the search, $s_{start} \in S$
S_{goal}	goal vertex of the search, $S_{goal} \in S$
$succ(s)$	set of neighbors of $s \in S$ that have line-of-sight to s, $succ(s) \subseteq S$
$c(s,s')$	straight-line distance between s and s′ (Both not necessarily vertices),
$lineofsight(s,s')$	Is true if and only if they have line-of-sight.
$h(s)$	estimated distance from the initial position to the final destination position. A heuristic function to calculate the estimated value is used.
$f(n)$	estimated cost from the starting point to the target point
$g(n)$	actual cost from the starting point to the current node n
$h(n)$	Heuristic function, which represents the estimated cost from the intermediate point n to the target point.

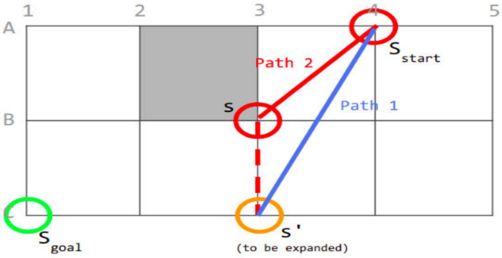


FIGURE 5. Grid path versus shortest path.

Theta* calculates trajectories utilizing propagating the information along the edges of the grid without restricting the trajectories to the nodes. Additionally, desirable properties of route planning techniques are added, such as visibility graphs and use of grids and visibility lines. The key difference between Theta* and A*, is that Theta* allows the vertex parent to be any else vertex, unlike A* where the parent must be a visible neighbor, updating the g-value and the parent of a neighbor visible, not expanded vertex s, considering the bifurcation in COMPUTECOST procedure shown in the list of notations in Table 1.

As shown in Figure 5, Theta* can consider paths 1 and 2, whereas A* will only consider path 1. This is because Theta* checks - during the expansion phase - for the line-of-sight between the vertices and their relative parents, while A* Post-Smoothing checks for line-of-sight only after it has formed a path already. The Theta* algorithm, like the A* algorithm, applies to static grid maps and its cost function expression as in (1).

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

Theta* is particularly beneficial in scenarios where the environment allows diagonal movements and where reducing unnecessary turns or zigzag paths is important. It can be applied in various applications, including augmented reality, video games, and robotics, to generate more efficient and visually pleasing paths. Theta* algorithm is described in Table 2.

V. PERFORMANCE EVALUATION

This section will evaluate the SINS_AR scheme performance from the user and admin perspectives.

A. SIMULATION TOOLS AND PROCESS STEPS

The following list of process steps:

1) MAP OF BUILDING MODEL

The first process of the proposed SINS_AR software is the map of the building model in 2D, as illustrated in Figure 6. The proposed SINS_AR performs some processes in the 3D

TABLE 2. **Theta* algorithm.**

```
procedure Main(void)
  $g(sstar) \leftarrow 0$
  $parent(ssstar \leftarrow sstar)$
  $open \leftarrow 0$
  $open.Insert(sstar, g(sstar + h(sstar)))$
  $closed \leftarrow 0$
  while $open 6= 0$ do
    $s \leftarrow open.Pop()$
    if $s = sgoal$ then
      return" path found"
    end if
    $closed \leftarrow closedU\{s\}$
    [UpdateBounds(s)]
    for each $s' \in succ(s)$ do
      if $s' \notin closed$ then
        if $s' \notin open$ then
          $g(s') \leftarrow \infty$
          $parent(s') \leftarrow NULL$
        end if
        UpdateVertex(s, s')
      end if
    end for
  end while
  return" no path found"
end procedure
procedure ComputeCost (s, s')
  if LineofSight (parents(s, s')) then
    // Path 2 //
    if $g(parent(s)) + c(parent(s), s') < g(s')$ then
      $parent(s') \leftarrow parent(s)$
      $g(s') \leftarrow g(parent(s)) + c(parent(s), s')$
    end if
  else
    // Path 1 //
    if $g(s) + c(s), s' < g(s')$ then
      $parent(s') \leftarrow s$
      $g(s') \leftarrow g(s) + c(s, s')$
    end if
  end if
end procedure
```

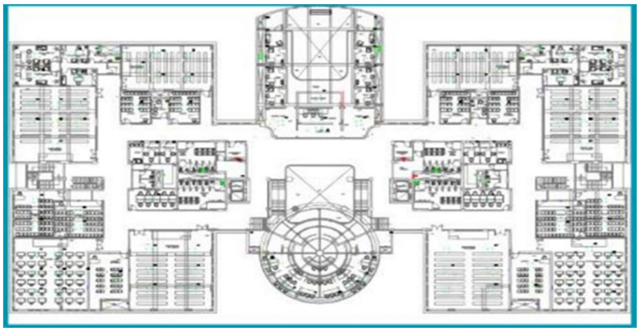


FIGURE 6. **The 2D model map.**

model map, as shown in Figure 7. So, Revit [29] is implemented for constructing the 3D model from the 2D model. Revit uses parametric modeling techniques, where changes to one aspect of the model automatically update related elements and views.

2) IMPLEMENTED UNITY

The second process is Implemented in Unity to support an environment to create the indoor navigation system for the proposed SINS_AR scheme. All the navigation tools needed for implementing a completed indoor navigation system using Unity [30] through various platforms, including desktop computers, mobile devices, consoles, virtual reality (VR) systems, and AR.

Key features of Unity include the following:

- Visual Editor: It allows developers to design game scenes, create levels, place objects, set up lighting, and configure other aspects of the game world
- Scripting: Unity supports scripting in C# (C Sharp), a powerful and widely used programming language. Developers can write custom code to control game behavior, implement game mechanics, handle user input, and create interactive experiences.
- Cross-Platform Development: With Unity, developers can build their games for multiple platforms from a single codebase. This allows games to be deployed on platforms such as Windows, macOS, iOS, Android, Xbox, PlayStation, and more.
- Physics Simulation: Unity includes a physics engine that allows developers to create realistic interactions between objects in the game world, including gravity, collisions, and forces.

3) UNPACKING PROCESS

The proposed SINS_AR scheme imported a 3D map into Unity and unpacked all the 3D objects. The best performance for the SINS_AR scheme is achieved by making the 3D map as light as possible so that all unneeded objects like the interior stairs at the halls, the ceiling, and the doors, which will not benefit the indoor navigation are removed to reduce map's size.

4) NAVIGATION PROCESS USING THETA*

The fourth process after unpacking is the navigation process using theta* to find the shortest path to the destination point from the start point of the navigation. To determine the possible destinations for the user to choose, SINS_AR sets a group of target cubes in front of the destinations we are working on and names them by the room numbers, as shown in Figure 8.

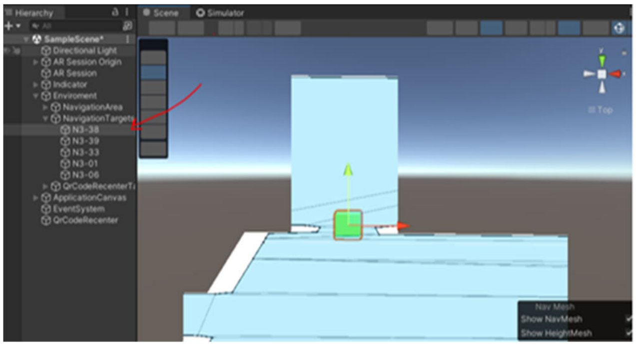


FIGURE 7. **Setting the target cubes at room position N3-38.**

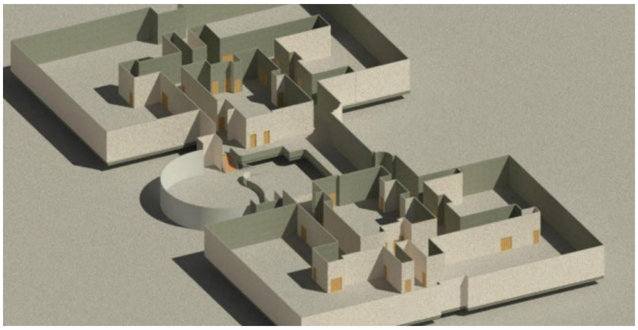


FIGURE 8. **The 3D model for the map on Revit.**

5) CREATING THE LINE RENDERING

Line Renderer is a component that allows you to render lines or curves in your view port scene. It's a useful tool for visualizing paths, trajectories, or any other line-based elements in SINS_AR view port as shown in Figure 9.

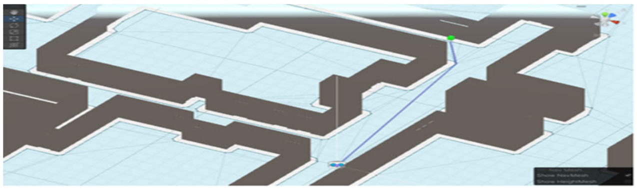


FIGURE 9. **The target cube from another view.**

6) REPOSITIONING USING QR CODE

The final process is repositioning using QR codes; by placing QR codes at strategic locations within an environment, users can easily scan these codes with their mobile devices to reposition the start point to their current position and recalculate the shortest path from their current positions till their desired target points as shown in Figure 10.

B. PERFORMANCE METRICS

A technical performance assessment was conducted to evaluate the technology's feasibility and efficiency. These terms are metrics that are the main scale to perform comparisons between the schemes: INS_AU [5], RFID_PR [8], A-GPS [4], [23], and the proposed SINS_AR scheme. Feasibility is determined by analyzing the application's ability to detect the walking speed. The response time, processing time, and accuracy are presented in the next subsection.

1) RESPONDING TIME

Responding time is between the query request's end and the response's beginning. Figure 11 shows that simulation of architectures has been done for different request numbers (30, 60, 100, and 200) per second. Obviously, when the number of requests per second increases, all schemes' response time increases rapidly, but the SINS_AR scheme achieves the least response time. SINS_AR is the most reliable than others. INS_AU is used to provide A* methods that are unavailable at Runtime. Because it is very complex to implement, it is not optimal when there are multiple targets so that the responding time is larger than SINS_AR.

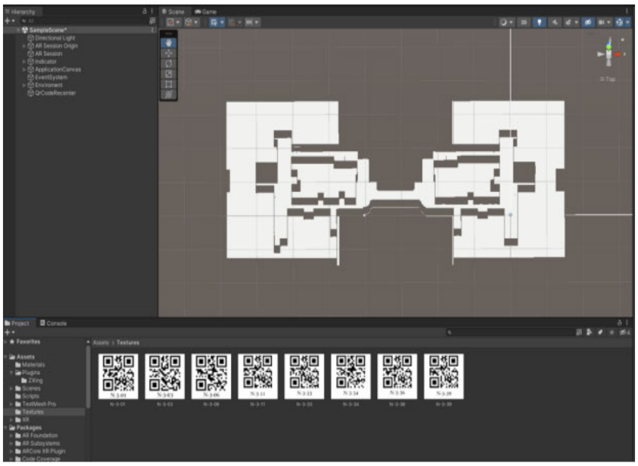
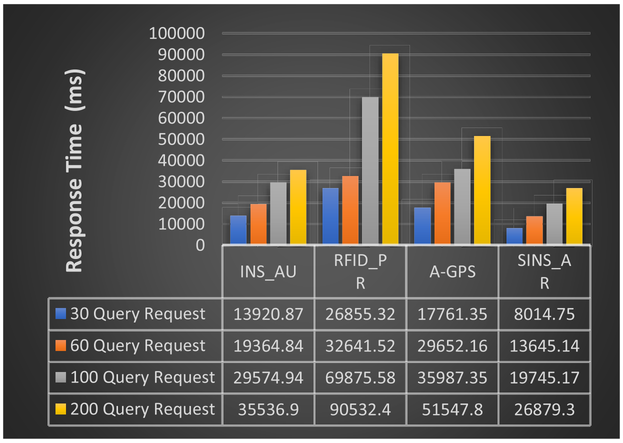


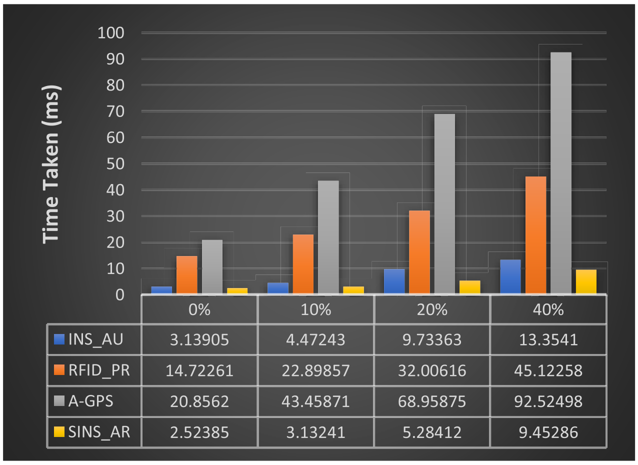
FIGURE 10. **QR Codes for repositioning the user.**



	INS_AU	RFID_PR	A-GPS	SINS_AR
■ 30 Query Request	13920.87	26855.32	17761.35	8014.75
■ 60 Query Request	19364.84	32641.52	29652.16	13645.14
■ 100 Query Request	29574.94	69875.58	35987.35	19745.17
■ 200 Query Request	35536.9	90532.4	51547.8	26879.3

FIGURE 11. **The responding time the comparison of the proposed system with state-of-the-art algorithms.**

RFID_PR also uses UHF-RFID technology that is presented when a robot equipped with a reader antenna moves over multiple trajectories, which may not be contiguous in time. Setup for the RFID_PR scheme requires the integration of the readers, tags, path management system, network, and building wiring, which can take a significant amount of time and resources to set up. So, RFID_PR consumes the highest amount of responding time when increasing the number of queries. Although A-GPS is an enhancing scheme of GPS, A-GPS uses information from more than one source while calculating device position so that the response time is larger than INS_AU.



	0%	10%	20%	40%
🟦 INS_AU	3.13905	4.47243	9.73363	13.3541
🟧 RFID_PR	14.72261	22.89857	32.00616	45.12258
⬜ A-GPS	20.8562	43.45871	68.95875	92.52498
🟨 SINS_AR	2.52385	3.13241	5.28412	9.45286

FIGURE 12. Runtime of each of the schemes to plot the paths on a user-designed map of dimensions 100 × 100.

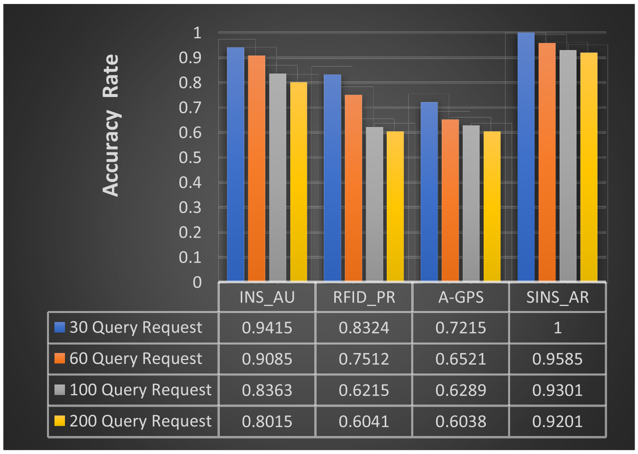
2) RUNTIME ANALYSIS

The schemes were tested based on the obstacle density of each map under consideration and the time taken to plot the path from a start node to a destination node taken at random on the desired map. Fig.12 shows the time each scheme consumes to detect the path on the map size of 100 × 100.

Observing the runtimes of each scheme to find the path from a given start node to the destination node based on varying obstacle densities, one can observe that SINS_AR takes the least amount of time to find the path to the goal then INS_AU, followed by RFID_PR and finally A-GPS. The least amount of Runtime occurred at SINS_AR because of the unpacked process of removing all unneeded objects to reduce the size of the map. The highest Runtime occurs at the A-GPS scheme because All barriers are a type of obstacle at the A-GPS scheme. A-GPS scheme followed by RFID_PR because it provides UHF-RFID that is not compatible with use when scanned environment evolve metal or water because these items can disrupt its signal. So, metal or water is considered a type of obstacle.

3) ACCURACY RATING

The accuracy rate can be expressed as the number of requested queries divided by the correct response queries number. So, the best performance is obtained when the accuracy rate value equals or is near 1. The worst case is assumed to happen at 200 query requests simultaneously, leading to a bottleneck formation. The results are shown in Figure 13. The performance of SINS_AR is dropped to be approximately less than 8% during the bottleneck of the highest query request numbers which is considered a very little and an acceptable variation. With variant request numbers, the accuracy rate of the proposed SINS_AR scheme value can always reach higher than 93%. While in the best case (only 30 requests), the accuracy can reach approximately 100%.



	INS_AU	RFID_PR	A-GPS	SINS_AR
🟦 30 Query Request	0.9415	0.8324	0.7215	1
🟧 60 Query Request	0.9085	0.7512	0.6521	0.9585
⬜ 100 Query Request	0.8363	0.6215	0.6289	0.9301
🟨 200 Query Request	0.8015	0.6041	0.6038	0.9201

FIGURE 13. The accuracy rate of the comparison of the proposed system with state-of-the-art algorithms.

VI. CONCLUSION

This paper introduces the solution for GPS problems in indoor environments. The proposed Smart Indoor Navigation System Using Augmented Reality called SINS_AR can enhance the accuracy and usability of indoor navigation solutions. In SINS_AR, and with the help of direction arrows augmented in the real world seen through smartphones, the user should be navigated in an unfamiliar indoor setting using the smart smartphone that scans a QR code to detect his positioning and select his desired destination. The proposed SINS_AR scheme calculates using Theta* pathfinding to detect the shortest path to the destination. A real traffic scenario of Sinai University in kantara branch at Ismailia City, Egypt, with variant node densities, has been considered to help analyze Indoor Navigation performance metrics. These metrics are response time, runtime analysis, accuracy rate, and path length analysis. The mentioned scenario has been applied and evaluated via the application that uses Revit, Unity, Visual Editor, and C# to support Unity scripting, Cross-Platform Development, and a physics engine that allows developers to create realistic interactions between objects in the game world. The analysis showed that the SINS_AR scheme achieved the least response time, making it the most reliable of the existing schemes. In addition, SINS_AR takes the least time to find the path to destination node and achieves the best accuracy rate. SINS_AR optimizes any-angle algorithms by tweaking the line-of-sight checks to reduce the time to find the path to eliminate unnecessary turns in free space. The ongoing and upcoming work focuses on applying security mechanisms when sending queries to cloud providers to preserve privacy.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this paper, where Diaa Salama and Deema Mohammed Alsekait 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 paper. Yasmin Alkady, Rawya Rizk: discussed the results and wrote the paper. Yasmin Alkady and Diaa Salama: discussed the results and revised the paper. All authors read and approved the work in this paper.

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