Vol. 4, No. 1; Jan – Mar (2025)

Quing: International Journal of Innovative Research in Science and Engineering

Available at https://quingpublications.com/journals/ijirse

Dynamic Augmented Reality Navigation System

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ARTICLE INFO

Received: 05-02-2025
Received in revised form: 20-03-2025
Accepted: 22-03-2025
Available online: 30-03-2025

Keywords:

Augmented Reality;
AR Navigation;
Google Maps API;
GPS;
Navigation;
Theta Pathfinding;
Unity 6.

ABSTRACT

Navigational challenges in large campus environments can make it difficult for visitors and students to find their way efficiently. This study presents an Augmented Reality (AR) navigation system. This system uses Unity 6, GPS, Theta pathfinding, and Google Maps API to provide a real-time AR-based navigation experience by integrating live location tracking and directional guidance through AR overlays. The system ensures an intuitive, interactive, and user-friendly navigation solution, improving accessibility and convenience within the campus. Our implementation demonstrates enhanced efficiency in pathfinding and user engagement in large-scale outdoor environments.

DOI: https://doi.org/10.54368/qijirse.4.1.0159

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1.0 INTRODUCTION

Navigating large and unfamiliar spaces can be overwhelming, especially for first-time visitors and individuals who require precise directions. Traditional navigation aids such as printed maps and signboards are often ineffective, requiring users to interpret complex layouts manually. Verbal directions from others can sometimes be inaccurate or incomplete. Furthermore, emergencies demand quick and precise navigation to critical locations such as medical centres and exits. These challenges highlight the need for a more efficient, intuitive, and interactive navigation solution.

Lightweight AR rendering techniques ensure smooth performance, even on mobile devices with limited processing power. Additionally, the integration of real-time data processing and dynamic rerouting capabilities allows users to receive updated guidance in case of unexpected path obstructions. This study explores the AR navigation system's design, development, and performance evaluation, emphasising its impact on improving accessibility and user convenience.

Beyond personal navigation, the AR navigation system has potential applications in event coordination and emergency response. The system can dynamically guide attendees to designated locations during large gatherings or public events, reducing confusion and congestion. For emergencies, such as fires or medical emergencies, the app can provide the fastest and safest routes to exits, first-aid stations, or emergency response points. Integrating this system with administrative tools can enhance security and efficiency, ensuring a well-coordinated response to various logistical challenges.

When users launch the application, their location is retrieved using GPS and the Google Maps API. The user selects their destination from predefined locations or manually inputs a custom location. The Theta* pathfinding algorithm calculates the shortest and most efficient route, considering any obstacles or restricted areas. Once the path is determined, AR overlays such as 3D directional arrows and waypoints appear on the user's mobile screen, guiding them step by step in real time. As the user moves, their position is continuously updated, ensuring accurate and dynamic navigation. If the user deviates from the suggested path, the system automatically recalculates a new route and updates the AR markers accordingly. Additionally, the app provides visual and audio cues to enhance accessibility, making navigation seamless and intuitive for all users, including those unfamiliar with the environment.

2.0 LITERATURE SURVEY

Augmented Reality (AR) enhances navigation by overlaying Digital elements onto real-world environments, improving user interactivity. Several studies integrated AR with GPS, sensor fusion, and SLAM techniques to enhance navigation. However, these systems face limitations, especially regarding accuracy, real-time processing, and scalability. Asraf *et al.* (2020) explored mobile AR navigation, integrating GPS with AR visualisation for real-time tracking. Their study emphasised AR overlays in improving navigation accuracy and interaction. Wu and Yu (2018) developed an AR navigation system using Baidu Maps and Unity3D, leveraging GPS and IMU sensors for real-time tracking. Hashimoto and Cohen (2021) introduced GNSS positioning with Kalman filtering to enhance navigation accuracy in structured environments. Batuwanthudawa and Jayasena (2020) designed a real-time location-based AR platform using marker-less AR with GPS, a compass, and an accelerometer. Their system enabled real-time updates, improving tracking and interactivity. Wagner *et al.* (2010) proposed a real-time AR tracking system to enhance navigation stability using feature-based tracking. Brata *et al.* (2024) integrated Visual Simultaneous Localisation and Mapping (VSLAM) with Google Street View to improve AR anchor placement. Mulloni *et al.* (2011) introduced an AR indoor navigation system with activity-based instructions, combining sparse localisation points and AR overlays for improved accuracy. Sandra *et al.* (2021) proposed a low-cost AR navigation system using virtual markers instead of GPS-based solutions, integrating image recognition, SLAM, and A* pathfinding for real-time indoor navigation. Alkady *et al.* (2024) developed the Smart Indoor Navigation System (SINS_AR), integrating SLAM with Theta* pathfinding to improve indoor positioning and reduce dependency on external markers, using feature-based tracking to enhance navigation stability by reducing GPS dependency. Schall *et al.* (2009) developed a global pose estimation system using multi-sensor fusion, integrating inertial sensors and a visual orientation tracker to improve AR positioning accuracy.

3.0 METHODOLOGY

The AR navigation system follows a structured development approach to ensure precise location tracking, optimised route planning, and immersive AR-based navigation assistance. The system integrates GPS technology, pathfinding algorithms, and AR visualisation to provide users with seamless and interactive guidance. The system architecture consists of three core components: positioning (localisation), Navigation (Path Planning), and Rendering (AR-based guidance). These components work together to provide users with an accurate and interactive navigation experience.

3.1 Positioning (Localisation)

The positioning module accurately determines the user's location within an environment. It utilises GPS technology to continuously update the user's coordinates, ensuring precise tracking. This module enables dynamic location updates, allowing seamless movement while maintaining accuracy and reliability.

3.2 Navigation (Path Planning)

The navigation module determines the most efficient route from the user's location to the destination. It utilises the Theta* pathfinding algorithm to compute the shortest and most optimal path while considering environmental constraints such as obstacles and restricted areas. The system updates in real time, ensuring dynamic adjustments as users move along the suggested route. Unlike static navigation systems, this module can instantly recalculate the path if the user deviates, providing seamless and uninterrupted guidance. By integrating GPS data with real-time user positioning, the module ensures precise and responsive navigation, offering users an intuitive and reliable wayfinding experience.

3.3 Rendering (AR-Based Guidance)

The rendering module provides users with an immersive and interactive navigation experience. It overlays 3D directional arrows onto the real-world environment using Augmented Reality (AR) technology. Developed with Unity 6 AR toolkit and AR Core, the system ensures precise spatial mapping and seamless AR interactions. The AR elements adjust to their real-time location dynamically as the user moves, ensuring smooth navigation guidance. If the user deviates from the suggested path, the system automatically recalculates the route and updates the AR overlays accordingly. The module enhances accessibility by providing intuitive and straightforward navigation assistance throughout the journey. The primary technologies involved include

Unity 6, AR Core, Google Maps API, Theta* pathfinding algorithm, GPS tracking, and Google Cloud services for spatial anchoring and real-time updates. The development environment is set up in Unity 6, providing robust AR development support, real-time 3D rendering, and cross-platform deployment. The AR Core SDK is integrated into Unity to enable real-world augmentation, allowing the system to overlay digital markers and navigation arrows onto the user's surroundings.

3. 4 Theta* Algorithm

Theta∗ is an optimisation of the A∗ algorithm that seeks to decrease the number of pointless turns or zigzag motions to increase the resulting pathways' efficiency and naturalness. It accomplishes this by implementing a method known as "theta pruning," which makes way for more straightforward routes. Euclidean Distance Heuristics, such as A∗ and Theta∗, estimate the cost from a particular node to the target using a heuristic function. Assuming a straight-line path between two points, the Euclidean distance between them is frequently employed as a heuristic.

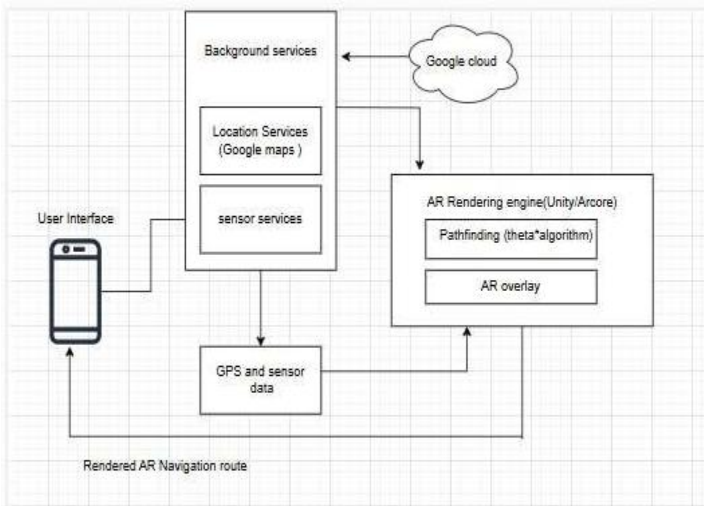
The idea of "line of sight" checks is incorporated into Theta. A clear line of sight between adjacent cells permits diagonal movements rather than rigidly following the environment's grid layout. This eliminates needless turns and permits more direct routes. The "theta pruning" technique is the primary optimisation in Theta∗. Theta looks for a direct line of sight between the parent and successor nodes while extending a node during search. If so, a more direct route to the successor node can be taken, and pointless intermediary nodes can be eliminated from the search.

When diagonal movements are permitted and theta pruning is employed, theta∗ produces smoother and more organic pathways than A∗. More aesthetically beautiful and practical designs can be achieved by cutting back on pointless turns and zigzag movements. If there is a legitimate path, it will always be found since Theta∗ ensures admissibility. Unlike A∗, it does not, however, guarantee optimality. Because of the theta pruning and line-of-sight checks, Theta∗ can occasionally result in less-than-ideal pathways than A∗. Nonetheless, the generated pathways are still typically of excellent quality.

For accurate location tracking, the system uses GPS technology and device sensor data to improve positioning accuracy. The Google Maps API is integrated to provide map data and geolocation services, ensuring real-time navigation updates. The Theta* pathfinding algorithm is implemented to calculate the shortest and most efficient path to the user's selected destination, dynamically adjusting the route in case of deviations. The backend services, responsible for processing location data and AR overlays, communicate with Google Cloud for enhanced spatial anchoring, ensuring that AR markers remain stable and precise across different user sessions. The setup begins with installing Unity 6 and configuring the AR Core SDK. The project requires enabling AR Foundation in Unity, which bridges Unity and AR Core. The Google Maps API is registered and integrated within Unity to fetch real-time location data. The GPS and sensor processing module is developed using C# scripts in Unity to capture user movements and enhance tracking accuracy. The AR rendering module is configured with custom 3D navigation arrows and UI elements, ensuring an intuitive user experience. The Theta* pathfinding algorithm uses graph-based computations to compute optimal routes based on real-world layouts dynamically. Testing and deployment require an Android or IOS device with AR Core support. The application is tested in real-world conditions to fine-tune accuracy, optimise AR overlays, and ensure smooth performance. Debugging tools such as Unity Profiler and Google Firebase Analytics help refine system performance, reducing lag and ensuring real-time responsiveness.

Figure 1

Methodology of the Research

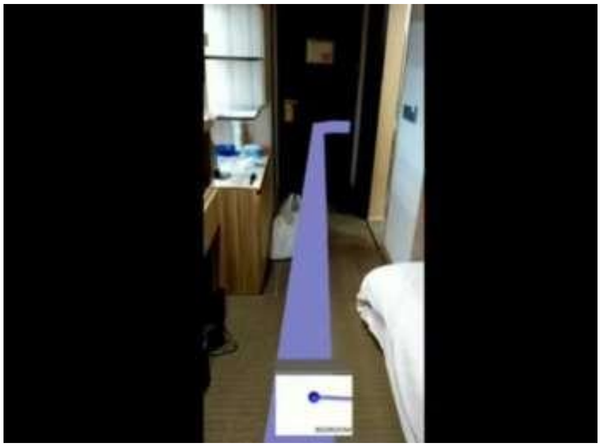


1) *User Interface (Mobile Application):* The user interacts with the system through a mobile app that displays the AR navigation route. The app receives GPS and sensor data from the device to determine the user's real-time location. Users select their destination, and the system calculates the shortest route.
2) *GPS and Sensor Data Processing:* The mobile device collects GPS coordinates and sensor data (such as accelerometer and gyroscope readings) to accurately track the user's movement. This data is sent to the Background Services for further processing.
3) *Background Services (Location & Sensor Services):* Background services handle real-time location fetching through the Google Maps API, process sensor inputs for improved accuracy, and interact with cloud-based spatial anchoring solutions. The system ensures real-time positioning and updates the user's path dynamically.
4) *AR Rendering Engine (Unity/AR Core):* The AR rendering engine, developed using Unity 6 and AR Core, handles pathfinding using the Theta* algorithm to calculate the optimal route and renders AR overlays, such as arrows and navigation markers, in the real-world environment. The AR elements update dynamically as the user moves, ensuring real-time guidance.
5) *Final Output:* AR Navigation Route: The system renders AR-based guidance onto the mobile screen, helping users navigate the college campus visually. If the user strays from the path, the system recalculates the route and updates the AR overlays accordingly.

The mobile app collects the user's location and sends it to background services. The Google Maps API provides map data, while sensor services refine accuracy. The Theta* algorithm determines the shortest path to the selected destination. The AR engine (Unity/AR Core) renders 3D navigation arrows onto the real-world view. The user follows the AR path, and if they move off-course, the system updates dynamically.

4.0 RESULT AND DISCUSSION

The user follows the AR path, and if they move off-course, the system updates dynamically. The AR navigation mobile app integrates Unity 6, GPS, Theta* pathfinding, and Google Maps API to provide real-time navigation assistance. The app detects the user's live location and dynamically generates the shortest path to the selected destination using the Theta* algorithm. AR arrows overlay the view, guiding users effectively, improving wayfinding, and reducing navigation confusion. Testing confirmed the app's accuracy in real-time tracking and pathfinding. However, minor AR object placement and GPS precision refinements could enhance the user experience.



5.0 PERFORMANCE METRICS

Table 1

Performance Metrics

Metrics	Theta*	Google Map Directions	A*
Accuracy (GPS Error)	<5m (with sensor Fusion)	<10m (GPS-dependent)	<5m
Pathfinding Efficiency	More directly, it considers visibility (LOS)	Road-based, not optimised for custom paths	Less direct, grid-based constraints
Latency (Path Recalculation)	<100ms	200- 500ms (API dependent)	150-300ms
Battery Consumption	<15% per hour	20-30% per hour	<15% per hour
Success Rate in Dense Areas	>90% (uses sensor fusion)	<80% (GPS interference issues)	>85%
Cost	Free (runs locally, no API cost)	Paid (Google Maps API charges per request)	Free

Since accuracy dictates how closely digital items match actual places, it is a crucial component of AR navigation. Theta* reduces positional errors to ≤ 5m by combining GPS with sensor fusion techniques, such as IMU (gyroscope and accelerometer) and camera-based localisation, to obtain high precision. On the other hand, Google Maps Directions primarily uses GPS, which is susceptible to atmospheric conditions, multipath errors, and urban canyons, frequently leading to mistakes of up to 10 meters. Although accurate in structured maps, traditional A* pathfinding might not dynamically adjust for obstacles in the actual world.

Pathfinding efficiency is the degree to which the algorithm finds the best path while considering practical limitations. Because Theta* considers line-of-sight (LOS) paths, it reduces needless detours and makes travel more direct, making it more effective for pedestrian navigation. Theta* can traverse open spaces like parks and designated pedestrian walkways, unlike Google Maps, which is limited to pre-established road networks. Because A* uses a grid-based methodology, it may produce less-than-ideal routes, particularly when diagonal movement is feasible but not explicitly specified in the grid.

6.0 CONCLUSION

By successfully utilising sensor fusion (GPS, IMU, and camera-based localisation) for increased accuracy, the AR-based outdoor navigation system with Theta* and Google Maps integration offers a productive and real-time navigation experience. In contrast to conventional navigation systems, Theta* improves pathfinding by taking line-of-sight (LOS) movement into account and enabling more efficient. This method covers the drawbacks of A*, which follows a precise grid-based route, and Google Maps, which is limited to specified roads. The system offers a user-friendly and interactive navigation solution combining augmented reality, real-time tracking, and optimised pathfinding. The system may be more reliable and scalable by adding offline functionality, improved obstacle recognition, and more precise mapping.

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