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An Augmented Reality-Based Indoor Navigation Framework Using Visual SLAM and Dynamic Path Planning

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***Abstract*—This research paper aims to develop an innovative marker-free AR indoor navigation system that utilizes smartphone sensors, SLAM-based localization, and the A* algorithm to compute the shortest path between a user's starting point and destination. The system leverages ARCore capabilities combined with built-in sensor data to deliver accurate navigation within large indoor environments. Initial experiments demonstrated stable tracking, responsive path visualization, and an overall improved user experience. The system was designed and tested inside the Computer Science and Engineering Department of MEA Engineering College. By overlaying virtual guidance cues such as arrows and labels on the user's smartphone screen, the system provides intuitive and seamless indoor navigation.**

I. Introduction

In today's world, rapid technological advancement has made people increasingly dependent on smart devices for their everyday activities. Smartphones, in particular, have become essential tools used for communication, entertainment, learning, and importantly, navigation. Most users rely on digital platforms such as Google Maps to travel from one place to another. These systems primarily operate using GPS(Global Positioning System), which functions effectively in open outdoor environments. However, GPS signals weaken or fail entirely inside enclosed spaces, making it unsuitable for navigation within large buildings or complex indoor environments [1].

This limitation has created a growing need for accurate and user-friendly indoor navigation solutions. Although several indoor positioning systems exist, many rely on external hardware such as beacons, RFID(Radio Frequency Identification) tags, QR markers, or specialized sensors, which increases deployment cost and system complexity [1] [2] [3]. To overcome these challenges, modern approaches are shifting toward Augmented Reality (AR) combined with Simultaneous Localization and Mapping (SLAM). These technologies utilize the smartphone's built-in camera and sensors to understand the environment and track the user's movement, enabling accurate, marker-free indoor navigation without requiring additional external devices. This makes AR-based indoor navigation a scalable, cost-effective, and intuitive alternative to traditional systems.

II. Literature Review

A. Augmented Reality-based Indoor Navigation using Unity Engine (Rokesh Maran B., Giridharan L., Krishnaveni R.).

The study titled "Augmented Reality-based Indoor Navigation using Unity Engine" introduces an indoor navigation approach that uses Unity3D, AR Foundation, and NavMesh to guide users through a virtual path projected onto real environments. The system overlays lines, markers, and interface elements directly in the camera view and operates without external infrastructure like Wi-Fi, BLE beacons, or QR markers, making it simple to deploy. While the method offers clear visual guidance, it depends on a pre-built 3D model of the building and basic ARCore plane detection, which limits accuracy and scalability in larger or changing indoor spaces. Overall, the paper demonstrates how AR can enhance indoor wayfinding but also reveals the need for more

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advanced, dynamic localization methods such as SLAM-based marker-free navigation [4].

B. The Implementation of Indoor Navigation Using Augmented Reality to Enhance Users Experience (UX) (Mashael M. Khayyat)

Khayyat's study presents an AR-based indoor navigation concept that focuses heavily on improving user experience by integrating virtual characters and computer vision to guide users inside real environments. The system, designed as the "Guide Me" application, uses AR to overlay navigation cues and employs a virtual assistant to make the navigation process more intuitive and engaging. The paper highlights how AR can enhance usability and emotional engagement, especially in large indoor areas such as university campuses. While the approach successfully improves user interaction through an enjoyable AR interface, it depends on Placenote servers, iPhone-specific tools, and static destination lists, which limits scalability and cross-platform implementation. Overall, the work demonstrates the potential of AR for interactive indoor navigation but shows the need for more advanced localization, multi-platform support, and dynamic map handling [5].

C. Indoor Navigation with Augmented Reality and BIM: A Marker-Based Approach for Locating Logistics Areas on Construction Sites(Maximilian Gehring, Pascal Mosler)

Gehring and Mosler present a BIM-integrated AR navigation system designed specifically for construction sites, where locating materials across multiple floors is often difficult and time-consuming. Their approach uses QR-code markers linked to BIM data to accurately position users and guide them to logistics storage areas through AR overlays. By relying entirely on BIM models—which include 3D geometry, logistics zones, and marker locations—the system becomes easy to adapt to changing construction layouts without extensive recalibration. While the marker-based method provides reliable positioning in environments unsuitable for SLAM or image recognition, it requires physical QR markers to remain intact and accessible, and navigation accuracy can suffer when AR tracking drifts, especially on dynamic construction sites. Overall, the study demonstrates how combining BIM and AR can streamline material search processes, though future work must address path blockages, recalibration needs, and support for more advanced tracking technologies [1].

D. AR-based Navigation Using Hybrid Map(Yanlei Gu, Woranipit Chidsin, and Igor Goncharenko)

Gu, Chidsin, and Goncharenko propose a marker-free AR indoor navigation system that integrates SLAM-generated 3D point clouds with traditional 2D floor maps to form a hybrid navigation map. Using ORB-SLAM and an RGB-D camera, the system builds a detailed point cloud of the environment and aligns it with floor-plan information to support accurate positioning and room-level guidance. This approach overcomes limitations of Wi-Fi, PDR, and marker-based methods by providing more reliable orientation and AR visualization in dynamic indoor spaces. Experimental evaluation showed that the system achieved satisfactory accuracy in about 75% of frames, demonstrating strong potential for first-person AR navigation. However, the hybrid map creation currently requires manual alignment, which limits scalability, and future improvements are needed for fully automated map generation and broader deployment [6].

Techniques Used	**Features**	**Effectiveness**
Unity3D + AR Foundation + NavMesh + Pre-built 3D Model	AR path visualization, virtual target tags, simple UI, uses manually built 3D indoor model	Good for small controlled environments; smooth visuals but limited accuracy in complex areas
Unity + Placenote Server + Virtual Character + Computer Vision	Virtual character guidance, cloud map storage, interactive UI	Strong in user engagement; effective for campus navigation but depends on server and environment stability
BIM + AR Foundation + QR-Code Markers	BIM-based indoor layout, QR marker positioning, accurate AR overlays	Highly accurate when markers are visible; suitable for construction logistics
SLAM (ORB-SLAM) + RGB-D Camera + Hybrid Map	Marker-free tracking, hybrid floor map + 3D point cloud, real-time pose estimation	High localization accuracy and robust performance in dynamic indoor spaces

TABLE I: Comparison of AR-based Indoor Navigation Techniques

III. METHODOLOGY

A. Overview

The proposed methodology focuses on designing and implementing a marker-free indoor navigation system using Augmented Reality (AR). The system combines real-time sensor data, SLAM-based localization, and optimal pathfinding algorithms to guide users inside indoor environments where GPS is unavailable. The methodology emphasizes accuracy, scalability, and user experience by overlaying navigation cues directly onto the real-world camera view. The complete workflow of the system is divided into environment mapping, localization, path planning, and AR-based visualization, ensuring seamless interaction between physical and virtual spaces.

B. IMU Sensor Testing and Data Analysis

The first phase of development focused on evaluating the smartphone's built-in Inertial Measurement Unit (IMU) sensors, which include the accelerometer, gyroscope, and orientation sensor. The team tested the accelerometer to measure linear motion and help with step detection. They used the gyroscope to track rotational movement and changes in direction. The application captured and displayed sensor readings to assess accuracy, responsiveness, and noise levels.

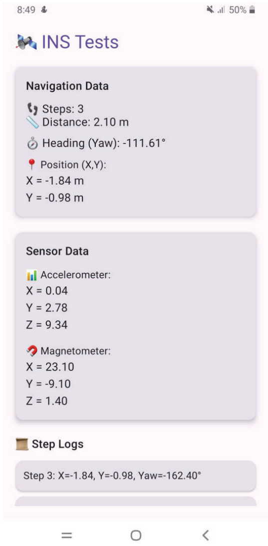

Fig. 1: Real-time IMU sensor data visualization interface

As shown in Fig. 1, the developed testing interface displayed real-time navigation data like step count, distance traveled, heading (yaw angle), and estimated position coordinates (X, Y). It also visualized raw sensor outputs from the accelerometer and magnetometer. This allowed for continuous monitoring of motion parameters. The step logs provided more insight into movement tracking and orientation updates. This testing phase ensured reliable real-time motion tracking before integrating localization techniques such as SLAM. The collected sensor data also served as a basis for improving movement stability and reducing drift during indoor navigation.

C. *System Initialization and Environment Setup*

Initially, the AR application is launched on a smartphone that supports ARCore or ARKit. The system initializes the AR session and activates the device camera and inertial sensors. The user is prompted to scan the surroundings so that the system can detect planes, surfaces, and visual feature points. During this phase, the environment is analyzed to establish a spatial reference frame, which serves as the foundation for accurate placement of virtual navigation elements. The indoor layout, such as corridors and intersections, is represented either through pre-mapped data or locally stored digital floor plans.

D. *Localization and Mapping Using SLAM*

To determine the real-time position of the user, the system employs Simultaneous Localization and Mapping (SLAM) techniques.[7] SLAM enables the device to continuously estimate its position while simultaneously building a spatial map of the indoor environment. The system extracts visual features from the camera feed and fuses them with inertial sensor data obtained from the accelerometer and gyroscope. This fusion improves robustness and reduces positional drift during user movement. The localization process is entirely marker-free, eliminating the need for QR codes or external infrastructure. As the user moves, the generated map is dynamically updated, allowing the system to maintain accurate tracking even in complex indoor layouts.

E. *Indoor Map Representation*

The indoor environment is modeled as a graph structure, where nodes represent navigable locations such as room entrances, corridor junctions, or staircases, and edges represent walkable paths between these locations.[8] Each edge is assigned a weight based on distance and accessibility. This representation allows efficient computation of routes and supports future extensions such as multi-floor navigation and accessibility-aware routing.

F. *Path Planning Using A* Algorithm*

Once the user selects a destination, the system computes the optimal route using the A* pathfinding algorithm. A* is chosen due to its efficiency and ability to find the shortest path while considering heuristic estimates. The algorithm evaluates each possible path using a cost function that combines the actual distance traveled and an estimated distance to the destination. This approach ensures faster convergence compared to traditional pathfinding methods. If the user deviates from the planned route, the system automatically recalculates a new path in real time, ensuring uninterrupted navigation guidance.

G. *Augmented Reality Visualization*

After computing the navigation path, the system overlays AR navigation cues onto the live camera feed. These cues include directional arrows, guiding lines, and destination indicators aligned with the real-world environment. The AR elements are rendered using Unity and AR Foundation, ensuring stable placement and smooth transitions. The visualization updates continuously based on the user's position and orientation, providing an intuitive first-person navigation experience. Optional audio instructions may also be included to assist users in following directions without constantly viewing the screen.

IV. RESULTS AND DISCUSSION

The AR-based indoor navigation app was successfully launched and tested on a smartphone that supports ARCore. During the testing phase, the system started the AR session and began scanning the indoor area with the device's camera and motion sensors. After it detected enough visual feature points, the system created a spatial map of the surroundings and resumed tracking, as shown by the status message on the interface.

Figure 5.1 shows the real-time navigation interface of the system. The application provides a live camera view with added navigation information. The top section of the interface displays key tracking parameters such as the device's position coordinates (x, y, z), orientation angles (yaw, pitch, roll), and the remaining distance to the chosen destination. This information helps check the accuracy of the AR tracking process and ensures that the localization module is working properly.

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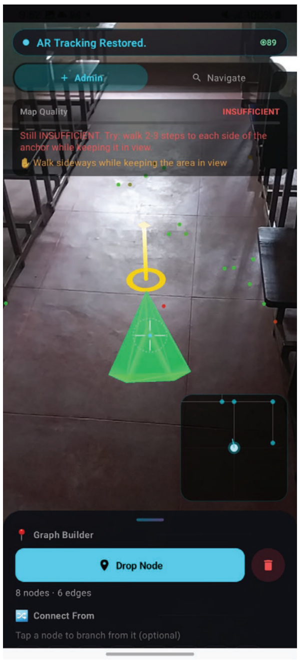

Fig. 2: Real-time AR-based indoor navigation interface showing tracking status, device position, path visualization, and destination nodes.

The interface includes navigation controls that let the user choose predefined indoor destinations (N1 - N5). Once a destination is chosen, the system calculates the best route using the A* pathfinding algorithm. The system shows the calculated path through augmented navigation cues. A small 2D minimap on the screen displays the locations of the user and the destination, along with the planned path. This combined visualization helps users grasp both the real-world direction and the route layout.

During navigation, the AR tracking stayed stable as the user moved through the environment. The system kept updating the user's position and orientation using SLAM-based visual-inertial tracking. The distance shown to the destination decreased as the user moved along the path. The system also let users recalibrate the spatial map with the "Resolve Floor Anchors" option to keep virtual objects aligned with the physical environment.

Therefore, the implementation was successful in the demonstration of the feasibility of using augmented reality for the purpose of real-time indoor navigation. The accuracy of the tracking of the devices and the calculation of the path were all effective in the demonstration of the feasibility of the proposed system for the purpose of navigation.

V. SUMMARY

This paper presents an Augmented Reality (AR)-based Indoor Navigation System designed to overcome the limitations of GPS in indoor environments. Unlike traditional methods such as static maps, QR codes, or Wi-Fi beacons, the proposed system combines SLAM-based localization and the A* pathfinding algorithm with AR visualization to provide real-time, intuitive navigation.

The system runs on AR-enabled smartphones, using the camera and inertial sensors for accurate positioning. The indoor layout is modeled as a graph, and the computed shortest path is displayed as AR directional overlays aligned with the real environment.

Experimental results show reliable localization, efficient route calculation, and smooth AR rendering. While dependent on AR-compatible devices and sensitive to low-light conditions, the system offers a scalable and user-friendly solution for complex indoor spaces such as campuses, hospitals, and malls.

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