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AR BASED INDOOR NAVIGATION: A REVIEW

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***Abstract**:* Indoor navigation systems have gained traction recently since GPS reception is extremely low inside buildings and enclosed spaces. These systems involve using technologies such as Wi-Fi, Bluetooth, Artificial Intelligence, or even simple hard-coded maps with pathfinding algorithms between two marked places. Furthermore, the method to present this system is also slowly moving away from traditional approaches such as using a map on the mobile screen, to methods like using AR.

This review paper intends to provide a comprehensive understanding and explore the potential of Augmented Reality enhanced Indoor Navigation Systems by comparing and contrasting various technologies, methodologies, and approaches. The paper also aims to provide a deeper insight into the capabilities, limitations, and future directions.

Keywords: Augmented Reality (AR); Artificial Intelligence (AI); Global Positioning Systems (GPS); Simultaneous Localisation and Mapping (SLAM)

INTRODUCTION

Indoor navigation comprises two major aspects: the positioning aspect and the navigation aspect. In enclosed spaces such as malls, airports, universities, and hospitals, they can be extremely challenging due to limited GPS signals. Not only that, even when the signals can be received, they can be unreliable and noisy. In order to overcome this issue, multiple systems have been proposed and developed. These systems leverage technologies including RFs, Wi-Fi, BLEs for positioning, and AI and SLAM alongside traditional pathfinding algorithms such as A-star (A*) for navigation.

However, the means to present navigational information has been based on typical 2D maps displayed on screens. While this method is intuitive, it lacks a proper spatial understanding of the environment due to a lack of depth. For this reason, Augmented Reality (AR) has been emerging as a promising alternative to the traditional approach of using maps, for enhancing indoor navigation. By overlaying indicators for directions onto a real-time environment, AR provides an immersive experience, increasing spatial awareness and depth of clarity, while also improving ease of navigation. This shift has garnered a lot of attention in both academic research and practical implementations.

Despite this, there are still several challenges left to overcome. Initial setup costs, unreliable accuracy of the systems, increased computational complexity with increased navigable area, signal interference being some of them. Additionally, practical issues such as scalability, security and user retention remain present.

This review paper aims to brief and address these points and explore the capabilities and limitations of some of the major approaches by offering a comprehensive understanding of the same. Thus, this paper seeks to contribute to the growing body of knowledge in this field.

LITERATURE REVIEW

Indoor Positioning

On the topic of positioning, there are multiple approaches for it in a closed environment. As highlighted in [1], these include satellite-based systems using a global network of satellites that emit radio signals in medium-earth orbit, magnetic-based systems that utilize magnetic distortions, sound-based systems that use ultrasonic sounds, etc. Outside of traditional location mapping and user localization using QR codes [2] [3], indoor positioning primarily utilizes radio frequency-based systems (RF-based systems).

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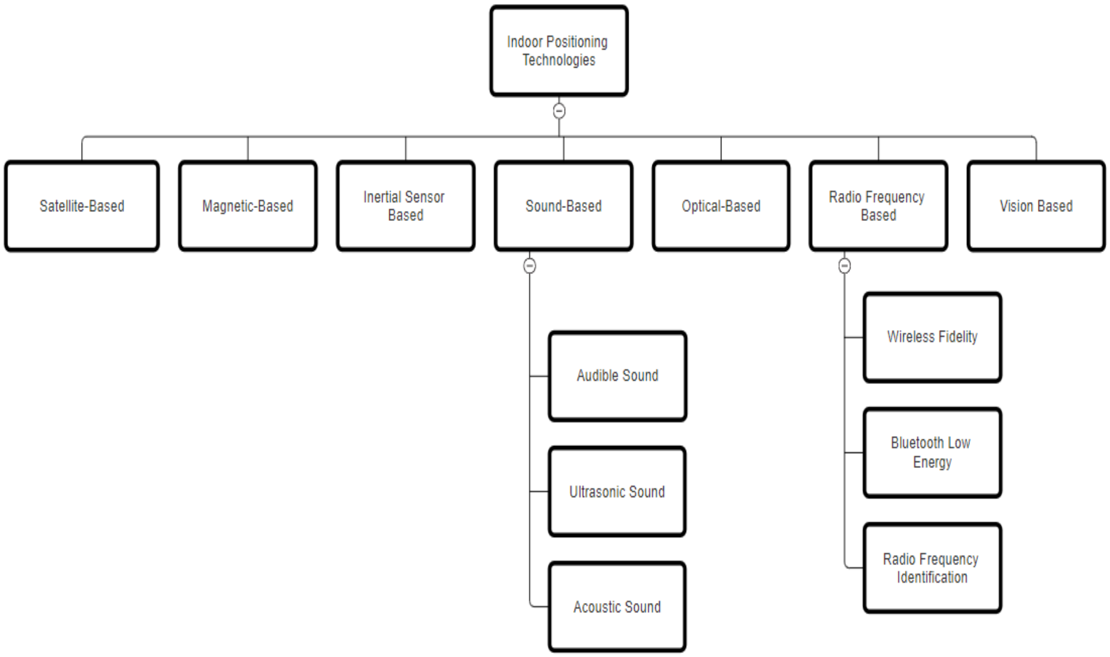

Figure: Different Indoor Positioning techniques

Radiofrequency-based systems use mixed narrow-band with spread-spectrum transmissions and are based on signal strength. Wi-Fi, BLE, RFID, and UWB are the most common choices for these systems. Bluetooth Low Energy (BLE), particularly Bluetooth 4.0, plays a crucial role in indoor positioning systems (IPS), offering an efficient and cost-effective alternative to GPS in indoor environments. BLE systems function through beacons that transmit unique identifiers detected by devices to estimate location. The authors of [9] emphasize the use of RSSI fingerprinting, where signal strengths from multiple beacons are mapped into a database to enable precise location tracking. This method ensures reliable navigation in complex structures like malls and airports, often achieving accuracy within one to three meters.

The authors of [9] underline the advantages of BLE, including low implementation costs, minimal power requirements, and high scalability. However, they also identify significant challenges, such as the need for optimal beacon placement to avoid signal gaps, susceptibility to interference from physical barriers or environmental factors, and the logistical burden of managing a fingerprinting database in evolving environments. Battery life limitations for beacons and mobile devices add another layer of complexity. To address these issues, the authors propose integrating BLE with cloud technology, enabling dynamic updates to beacon configurations and floor maps. Combined with a user-friendly mobile application, this approach offers a robust and scalable solution, advancing BLE's potential in overcoming GPS limitations indoors.

The authors of [1] also highlight the challenges encountered with these systems. Algorithms like Trilateration, RSSI, and Time-of-Flight (ToF) have inherent limitations in terms of accuracy because of environmental influences like interferences, signal reflections, and signal degradation. Achieving high-precision localization requires extremely sophisticated calibrations and optimizations. Not only that, for high-traffic zones the need to process large amounts of real-time data from multiple sensors can place significant computational demands, leading to delays or errors. Environmental changes and obstructions can also cause latency issues.

Navigation

On the topic of navigation, there are two main approaches to route planning: through Artificial Intelligence and through SLAM. Traditional shortest-path algorithms are also used occasionally in tandem with these technologies.

Artificial Intelligence has significantly improved indoor navigation, overcoming challenges such as energy efficiency and environmental noise, as highlighted in [4]. One of the earliest frameworks for this purpose was *LearnLoc* in 2015, which introduced KNN and DNN-based machine learning models for high-accuracy navigation. This was followed by CNN-LOC which converted fingerprints to images, outperforming DNN-based solutions. The following years saw multiple more frameworks for this purpose, such as QuickLoc, CHISEL, STELLAR, and many more that solved a multitude of problems, resulting in greatly improved accuracy, reduced energy consumption, and scalability. The researchers of [4] also highlight that there remain a multitude of challenges yet to be addressed for long-term stability and to counter environmental uncertainty.

Simultaneous Localization and Mapping (SLAM) is the concept of incrementally generating a map of an environment while simultaneously keeping track of the current location in that environment. As noted in [5], recent years have seen rapid progress and development of practical solutions and implementations of the SLAM technology. Being able to work in unknown environments renders this technology pre-made map independent. SLAM is generally used in tandem with the A* algorithm, as done by the researchers in [2], [3] and [6]. The

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A* algorithm is a best-first search algorithm combining aspects of Dijkstra's Algorithm as well as Greedy Algorithms. Typically, QR-code-based or BLE beacon-based positioning systems are used for positioning, after which SLAM and A* algorithm handles localization and routing. This method is fast, reliable, and works in unknown environments well, but faces challenges in the form of extremely high computational demand, sensor dependency, implementation complexity as well as resource hungriness.

Satellite-based - The most popular system for outdoor systems is the Satellite-Based. It is based on a global network of satellites that transmit radio signals in medium-earth orbit
Magnetic-based- To determine the locations which relate to magnetic indoor positioning, the use of geomagnetic fields has been distorted [1]

Inertial Sensor-based Sensors- based on inertia and associated measurement principles are known as inertial sensors. Accelerometers and gyroscopes are an example of inertial sensors. It does not require any external references and installation since it does not depend on the environment

Sound-based - Another technology used for localization systems is Sound-Based which is normally used in underwater monitoring and tracking. This technology can be classified into three categories which are Audible Sound, Ultrasonic, and Acoustic Sound. Sound waves travel at a slower rate than electromagnetic waves leading to the major problem which is to make time synchronization easier

Optical based- Optical-Based positioning used for localization is normally in the form of an Electro-Magnetic (EM) spectrum since the techniques and challenges are quite different. This system is a flexible navigation system for deep space operations. Optical positioning can be characterized into two, which are Infrared (IR) and Visible Light Communications (VLC)

The authors of [8] proposed an implementation of a 4D fast SLAM including volumetric sum of the UAV to implement a 4D fast SLAM (Simultaneous Localization and Mapping) algorithm, incorporating volumetric data to optimize UAV navigation in dynamic environments. The study bridged the gap between traditional 3D SLAM and complex 6D SLAM, offering a more computationally feasible solution tailored for UAV operations, although it was still hindered by challenges such as large computational resource requirements as well as sensor dependencies.

DISCUSSION

The field of AR-based indoor navigation systems has really flourished significantly during recent years with considerable progress achieved with advancements within positioning, navigation, and user interface technologies. The reviewed pieces of literature indicated that each form of indoor navigation has its strengths and weaknesses as well.

Positioning systems are essentially the skeleton of indoor navigation. RF-based methods, such as BLE, are popular because it is not expensive and can easily be integrated into existing infrastructures.

As demonstrated by [1], BLE beacons can reach relatively high accuracies at low costs but suffer from signal degradation and interference in complex environments. In contrast, QR code-based systems are shown to be rather straightforward and user-friendly in [2] and [3] but significantly suffer with initial setup and change in the physical environment. Due to the arrival of Artificial Intelligence (AI) and Simultaneous Localization and Mapping (SLAM) technologies, the navigation component has evolved. The AI frameworks discussed in [4] as CNN-LOC and QuickLoc have been able to provide enormous advancements in indoor navigation in terms of precision and reduced energy usage. Issues that remain challenging include the scalability and adaptability of these systems in changing environments.

In contrast, SLAM is known to enable efficient navigation through unknown spaces as it maintains an environmental map while continuously trying to estimate the location of the user, as discussed in [5]. However, its huge computational costs and dependence on sensors present serious limitations for widespread adoption.

Comparison: AI vs SLAM+A* technique

Aspect	**AI-Based Navigation**	**SLAM + A***
Accuracy	High but dependent on training data.	Accurate in dynamic environments.
Scalability	Computationally intensive training.	Limited by sensor and processing.
Adaptability	Sensitive to environmental changes.	Handles dynamic environments better.
Complexity	Requires ML expertise.	High sensor and algorithm overhead.
Real-Time Use	Latency in adapting to changes.	Resource-heavy real-time mapping.

The use of AR in navigation information presentation removes the critical constraint of conventional approaches through spatial cognition. For example, 3D directional cues can be superimposed over real-world environments by using systems such as ARBIN described in [6]. Enhanced user satisfaction and reduced cognitive load result from using such technology. Signal interference and device compatibility issues, despite being identified in [6], must be overcome for them to become popular. One of the key observations across the works reviewed is that there is an inverse relationship between cost, complexity, and accuracy. The cheapest solutions, such as QR code-based solutions, are quite simple to implement but lack both the flexibility and scalability of AI or SLAM-based solutions. Other practical considerations that include environmental

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changes, user retention, and computational efficiency remain persistent issues that require novel solutions.

Challenges and Limitations of Various Processes

The authors of [7] identify significant challenges in evaluating augmented reality (AR) systems, particularly due to the lack of standardization and universal frameworks. Traditional human-computer interaction (HCI) methods often fall short for AR's multidimensional and multimodal interfaces, leaving a gap in comprehensive guidelines for diverse AR applications. The heterogeneity of AR systems further complicates evaluation, as varied hardware platforms and interaction modalities make it difficult to establish universal criteria. This diversity limits the consistency and comparability of assessments across platforms. User-centric challenges also arise, including difficulty in engaging representative user groups and effectively measuring unique AR experiences like immersion and collaboration, which are not addressed by traditional usability metrics. Additionally, resource constraints often confine evaluations to small-scale studies, limiting their rigor and generalizability. The authors of [7] also underscore the need for standardized, scalable evaluation methods to address these challenges and ensure robust AR system assessments.

Technique	**Key Challenges**
BLE Positioning	Signal interference; delays in high-traffic zones.
QR Codes	Setup effort; inflexible to changes.
AI Navigation	High training and computational needs.
SLAM Technology	High computational demand; sensor dependence.
A Algorithm*	Struggles with real-time recalculations in dynamic spaces.
AR Interfaces	Hardware limitations; risk of cognitive overload.

CONCLUSION:

This review integrates the then-existing body of research relating to AR-based indoor navigation systems, with positioning technology, navigation methodology, and AR interface interaction. The combination of BLE and QR code-based positioning with further advanced navigation techniques such as AI and SLAM has greatly improved the potential of indoor navigation. Moreover, this AR has become a pioneering medium for the delivery of navigation information, providing an immersed and intuitive user experience.

Despite these developments, there are still several challenges that need to be overcome. These include computational inefficiencies, environmental adaptability, and signal reliability. Future research should, therefore, focus on hybrid approaches that combine the cost-efficiency of simpler systems with the accuracy and scalability of advanced technologies. Other issues that will be key to widespread adoption include hardware compatibility and user-centric design considerations.

Such literature examination forms a solid base for further research and the promise of edge computing for instant processing, along with AI-based approaches for flexible and scalable indoor navigation frameworks. Augmented reality technology's evolution and smooth merge into the navigation system puts within our grasp the dream of attaining the vision of truly efficient and user-centric indoor navigation systems.

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