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Accurate Indoor Localization and Path Guidance Using WiFi Fingerprinting Techniques

Mrs. G. Jeyasri[1], Subanu R. S[2], Pragatheeswari K[3], Vinothini N[4]
Assistant Professor, Department of Information Technology[1]
Students, Final Year, Department of Information Technology[2-4]
Anjalai Ammal-Mahalingam Engineering College, Thiruvarur, Tamilnadu, India.

Abstract: *In moment's connected geography, indoor navigation is essential for delivering superior user gests in extensive and intricate surroundings similar as hospitals, shopping promenades, airfields, and university premises . Traditional GPS-based positioning systems often fall short indoors, struggling to deliver reliable accuracy due to signal degradation and physical obstructions. This study presents a robust Wi-Fi-based indoor navigation system that leverages fingerprinting and machine learning algorithms to precisely predict a user's location within a building. The system effectively collects Wi-Fi signal data (Received Signal Strength Indicator, RSSI) from existing access points and seamlessly matches this information with a pre-trained model to accurately determine real-time user positioning. A dynamic floorplan interface is employed to not only visualize user movement but also to provide efficient, destination-oriented routing. Notably, this system operates without the need for extra hardware and is designed to continuously adapt to changes in the environment, maintaining optimal performance at all times with its superior scalability and precision, the proposed method is a reliable and transformative solution for advancing smart indoor environments.*

Keywords: Indoor Positioning, Wi-Fi Fingerprinting, RSSI, CSI, Real-time Localization, Floorplan Navigation

I. INTRODUCTION

Modern applications rely heavily on navigation to allow users to navigate through complicated environments with ease. Although GPS has transformed outdoor navigation, its effectiveness diminishes indoors because satellite signals cannot effectively penetrate walls and enclosed environments. To overcome this limitation, various alternative technologies—such as Bluetooth Low Energy (BLE), Ultra-Wideband (UWB), and Radio Frequency Identification (RFID)—have been investigated. However, these solutions typically depend on specialized hardware or dedicated infrastructure, leading to higher installation and maintenance costs, which in turn hinder their scalability in practical applications.

Wi-Fi-based indoor positioning has emerged as a practical and cost-effective alternative, leveraging the existing wireless infrastructure commonly available in buildings. One of the most extensively used ways in this sphere is Wi-Fi characteristic, which relies on the entered Signal Strength Indicator(RSSI) values from multiple access points to produce unique signal "fingerprints" for different locales . In the proposed system, these fingerprints are collected and used to train a machine learning model able of directly prognosticating a user's current position. This model is then employed in real-time to match live Wi-Fi data from a user's device to known positions, thereby enabling precise and continuous localization.

To enhance user experience, the system incorporates an interactive visual interface that overlays the user's position on a digital floorplan and provides turn- by- turn navigation to a asked position. Compared to traditional signal-distance methods, fingerprinting combined with machine learning offers greater resilience to indoor signal fluctuations and environmental changes. This system enables real-time path planning, multi-floor navigation, and adaptive fingerprint updates—all using only a smartphone with Wi-Fi, without requiring any additional sensors or external devices. Because of this, the method is very scalable, easy to use, and appropriate for implementation in malls, hospitals, airports, smart buildings, and university campuses.

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II. METHODOLOGY

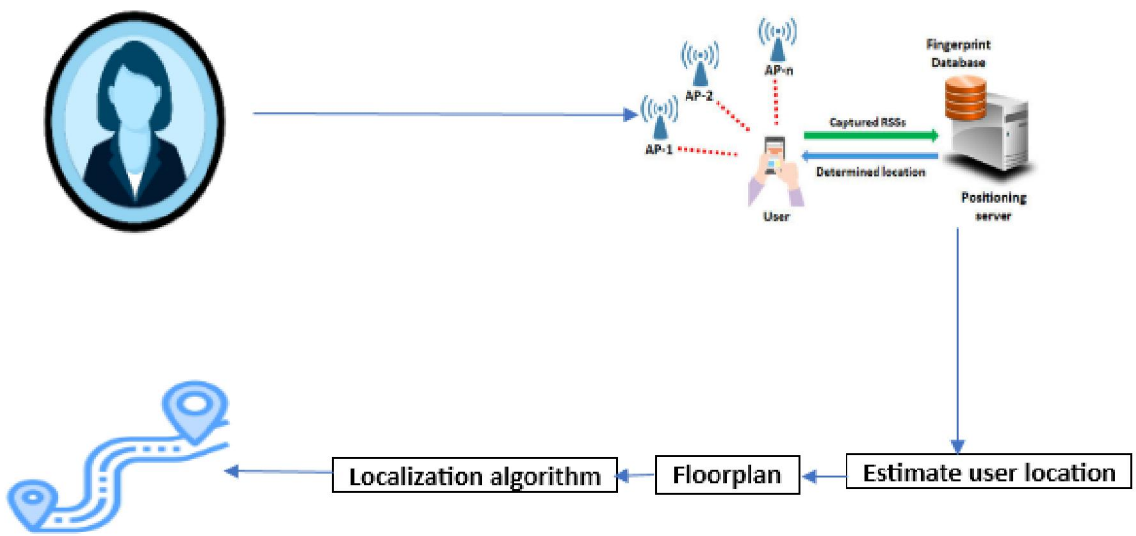
Wi-Fi Fingerprinting

Fingerprinting is carried out in two stages: the offline phase for data collection and the online phase for real-time positioning. In the offline phase, Wi-Fi signal strengths (RSSI) are recorded at various known locations to form a training dataset. This information is compared with live signal measurements from the user's device to determine the user's position during the online phase.

Machine Learning for Localization

Random Forest, an ensemble machine learning algorithm, is used to map Received Signal Strength Indicator (RSSI) values from multiple access points to specific physical coordinates, enabling accurate indoor Wi-Fi-based localization. It works by training multiple decision trees that learn the correlation between known locations and signal intensity on subsets of the Wi-Fi fingerprint dataset. In the online phase, real-time signal readings from the user's device are matched against pre-collected data to pinpoint the user's location. Its ability to handle noisy, high-dimensional data and missing values makes it highly effective in dynamic indoor environments where Wi-Fi signals often fluctuate.

System Architecture



III. LIST OF MODULES

1. Signal Collection:

This module involves periodic scanning of the wireless environment using the device's Wi-Fi adapter to detect nearby Access Points (APs) and log their corresponding RSSI values. In the training phase, each Wi-Fi scan is labeled with exact location coordinates, creating a fingerprint database that forms the basis for training the localization model.

2. Data Preprocessing:

Preprocessing involves normalizing RSSI values, addressing missing or undetected access points, and applying noise-reduction techniques to enhance the consistency and reliability of the signal data.Feature selection may also be applied to optimize model input by discarding unstable or redundant APs.

3. Localization Algorithm:

To precisely leverages machine learning models—primarily Random Forests—to predict user position based on real-time RSSI vectors. The models are trained using the fingerprint database and support extensions to alternative or ensemble approaches for enhanced accuracy in dynamic conditions.

4. Path Planning and Navigation:

The shortest-path method A* is used to compute optimal routes on a graph-based floorplan. The system updates the route in real-time as the user moves and can incorporate additional sensor data to maintain navigation continuity in areas with weak signal coverage.

IV. CONCLUSION

To achieve accurate real-time localization, this study proposes a Wi-Fi-based indoor navigation system that leverages the existing wireless infrastructure. By utilizing machine learning and signal fingerprinting, the system is applicable to a wide range of scenarios and does not require expensive hardware.The incorporation of a visual floorplan and pathfinding further enhances user experience. The system demonstrates robustness across different indoor settings, showing promising results in both small and large-scale trials.

V. FUTURE SCOPE

Future enhancements to the indoor navigation system can focus on improving scalability, user experience, and contextual awareness. One promising approach is crowdsourced fingerprint updates, where user devices automatically collect and upload signal data to keep the fingerprint database accurate and up-to-date without manual intervention. Additionally, extending the system to support 3D multi-floor navigation would allow users to seamlessly navigate across different levels of a building, incorporating elements such as elevators and staircases. Augmented Reality (AR) can also be integrated to provide visual cues overlaid through smartphone cameras, creating a more intuitive and immersive navigation experience that helps users better understand their surroundings in real time.

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