

Comparison Analysis on Campus Navigation System Using Different Pathfinding Algorithms

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Abstract—The examination in this research paper discusses modern advancements. Research has evaluated multiple technological solutions which improve campus navigation systems. New technical solutions have been developed to manage the navigation problems which affect both inside buildings and outside areas. outdoor navigation in university environments. Twenty research papers present various methods to handle campus navigation through their extensive investigation. Research explores various technological solutions for campus navigation which include interactive web-based maps alongside special systems designed for users with disabilities. specialized systems for users with disabilities. Key innovations The implemented systems adopt technology integration through GPS alongside Bluetooth. Low Energy (BLE) beacons, voice recognition, and adaptive interfaces. The assessment presents advanced methods that utilize the algorithms The pathfinding algorithms under study involve Floyd-Warshall together with Dijkstra. The systems offer personalized navigation solutions alongside other features which match with user requirements. These systems supply assistance for students who require help with vision. Findings indicate significant improvements in accessibility, user experience, and independence through these navigation technologies, with future The research dives into ways of improving real-time positional accuracy alongside other enhancement targets. The system will receive real-time updates and introduce new technologies together with augmented reality into its framework. reality.

Keywords :Indoor navigation, campus wayfinding, QR positioning, BLE beacons, Floyd-Warshall algorithm, Dijkstra algorithm, A* algorithm, multilateration, fingerprinting, accessibility design, offline navigation, Web GIS, hierarchical maps, network analysis, multi-modal positioning

I. INTRODUCTION

The complex multi-building university campus architecture presents severe indoor navigation challenges to today's students [1]. The effectiveness of Global Positioning System (GPS) technology is compromised when signals are interfered with indoors [1]. There is a comprehensive list of challenges that involves signal interference problems with indoor positioning [1], disability user-specific solutions [1], and inefficient campus internet services [1]. There are different groups such as students and visitors and faculty members that face challenges in effectively navigating facilities on the campus and this impairment affects individuals with disabilities the most [2]. The complexity of the campus denies new students the ability to identify their building locations due to growing student populations and facility expansion based on Kebede



Fig. 1. CUCNS Architecture

and Dessalegn [3]. Integration problems between outdoor and indoor navigation systems offer additional complexities [4]. The review articles introduce campus navigation systems using Quick Response (QR) code technology [1] and Bluetooth Low Energy (BLE) beacon networks [2], offline navigation systems [5], combined indoor-outdoor system architectures [4], disability user-specific systems [6], and web Geographic Information System (GIS) deployment [3]. We have developed an inclusive framework which integrates different positioning technologies with pathfinding algorithms and accessibility features and online-offline hybrid capabilities to tackle current challenges in campus navigation systems.

II. LITERATURE REVIEW

Some solutions have been suggested to deal with the indoor navigation issue in campus. Gryzun et al. [1] designed a web application that used QR codes for location identification and the Floyd-Warshall algorithm for shortest path finding. Multi-language interactive maps with vector graphics to draw paths were their solution at Simon Kuznets Kharkiv National University, with the caveat of a limitation in the representation of multi-floor routes. Pilski et al. [2] approached the usage of BLE transmitters for location of the user differently. They used a hierarchical building map framework and employed the use of multilateration and fingerprint methods to achieve accurate positioning. Path computation was achieved by the use of Dijkstra and A* algorithms on a Neo4j graph database, particularly well-suited for complex indoor environments. Profiles for different categories of disabilities (blind, deaf, wheelchair-bound) were also developed with notification personalization. Their system featured emergency capabilities in the form

of hazard detection sensors, demonstrating the capability of navigation systems to meet both wayfinding and safety requirements for people with disabilities. Kebede and Dessalegn [3] considered campus navigation from a GIS perspective and developed a web-based system for Wachemo University in Ethiopia. They used ArcGIS Network Analyst to optimize routes and incorporated aerial imagery for visualization. Their implementation demonstrated web-based delivery to be feasible for campus navigation, accessed using standard web browsers without requiring special applications. Smooth transfer between different environments is the basis of effective campus mobility. Bagul et al. [4] proposed a hybrid system with GPS for mobility outdoors and BLE beacons for mobility indoors. Their mathematical model defined the interactions between the system components, creating a common platform that ensured smoothness in the process of transferring the users from outdoor environments to buildings. In terms of connectivity limitations, Sparsh et al. [5] had proposed an offline campus navigation system using voice recognition and text search functionality. Their system stored maps and location data in a grid-based data structure and hash tables for efficient lookup and was able to run without internet connectivity. While sufficient for basic navigation, they acknowledged limitations in storage requirements and real-time updates with respect to online systems. Wayfinding systems for disabled users have been encouraging. Olaleye et al. [6] tested a specialized system for blind students at the Federal College of Education in Nigeria. Their system was a GPS-based smart cane with embedded ultrasonic sensors and voice directions in a Nigerian accent. User trials were 100

Throughout the works under review, some common trends in technology can be seen. Location identification increasingly uses more than one technology (QR [1], BLE [2], GPS [4]) to better counter the limitation of single approaches. Pathfinding algorithms have moved beyond mere shortest path computation to include accessibility factors and user preference [1, 2]. User interfaces more and more support varying requirements, i.e., accessibility requirements [2, 6]. Greater emphasis is also placed on offline capability [5] and indoor-outdoor transition smoothness [4]. Even with such developments, challenges remain in the accuracy of indoor positioning, visualization over multiple floors, battery life for mobile solutions, and integration of real-time updates with offline capability. Such limitations present good opportunities for campus navigation system research in the future. Some solutions have been suggested to deal with the indoor navigation issue in campus. Gryzun et al. [1] designed a web application that used QR codes for location identification and the Floyd-Warshall algorithm for shortest path finding. Multi-language interactive maps with vector graphics to draw paths were their solution at Simon Kuznets Kharkiv National University, with the caveat of a limitation in the representation of multi-floor routes. Pilski et al. [2] approached the usage of BLE transmitters for location of the user differently. They used a hierarchical building map framework and employed the use of multilateration and fingerprint methods to achieve accurate positioning. Path computation was achieved by the

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III. METHODOLOGY

A. Research Design and Approach

The research uses a mixed-methods design with quantitative and qualitative approaches to create and test a holistic campus navigation system. The research takes a systematic

development life cycle with requirements analysis, design, implementation, and evaluation stages.

B. System Architecture

The system architecture proposed is five interrelated modules:

1. Data Management Module : The Data Management Module manages all persistent data needed for the system to operate. It incorporates hierarchical building maps [1] that describe the spatial layout of campus buildings, such as multi-story buildings, corridors, rooms, and areas of interest. Location metadata is kept in JavaScript Object Notation (JSON) format [1], offering a lightweight and adaptable framework for expressing locations, their properties, and relationships. The module handles beacon data and positioning information [2], such as calibration parameters, signal strength references, and location mappings. Moreover, it has a graph-based model of navigation routes [2], storing potential routes, distances, and accessibility properties in a structured network that facilitates effective pathfinding algorithms.

2. Positioning Module : The Positioning Module calculates user location using several complementary technologies. Outdoor positioning is achieved using GPS technology [4]. Indoor positioning is achieved using several methods in combination. QR code-based location identification [1] provides accurate positioning when users scan codes mounted at strategic points across buildings. BLE beacon triangulation with multilateration algorithms [2] offers real-time positioning since users are in constant motion across beacon-covered spaces, computing location from received signal strength from several beacons. Radio-Frequency Identification (RFID)-based localization is applied to targeted entry points [5], and it identifies locations immediately when users cross equipped doorways or checkpoints.

3. Pathfinding Module : The Pathfinding Module supports several algorithms tailored to various navigation contexts. The Floyd-Warshall algorithm [1] offers general shortest path calculation over the entire campus map, pre-calculating optimal paths between all pairs of locations for quick response to navigation queries. Dijkstra and A* algorithms work on the graph database [2], providing more adaptive pathfinding that can take into account real-time constraints and user preferences. For external routes, network analysis algorithms [3] compute paths over campus terrain, taking into account parameters such as distance, terrain, and accessibility needs.

4. User Interface Module : The User Interface Module provides an adaptive layout that dynamically changes to accommodate varying device types and screen sizes [1], maintaining uniform usability across desktop, tablet, and mobile devices. Multi-language support with localization capabilities [1] ensures the system can be used by international users and visitors. Accessibility features respond to the demands of users having multiple disabilities [2, 6]. Auditory guidance with controllable loudness helps vision-impaired users with turn-by-turn instructions and position announcements. Hearing-impaired users are benefited from visual alarms and

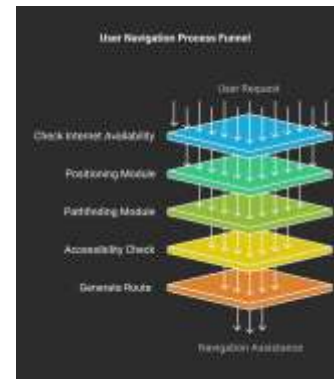


Fig. 2. CUCNS Methodology flowchart

vibration responses to provide guidance on navigation in an alternative sensing method. The priority of the route being made accessible for people on wheelchairs ensures guidance information for navigation away from ramps, slopes, and other obstruction items for impaired users.

5. User Interface Module : The Integration Module supports smooth switching between indoor and outdoor navigation [4], ensuring continuity as people transfer between buildings and open campuses. Offline data caching supports functionality in the absence of internet connectivity [5], caching key navigation data locally on user devices. An emergency notification system integration [2] increases campus security, notifying users of hazards, closures, and emergency conditions that might impact navigation

C. Data Collection Methods

C.1 Primary Data Collection : Primary data collection entails campus layout mapping with GPS for outdoor components [1], which offers precise geospatial coordinates for buildings, walkways, and outdoor facilities. Indoor space measurement and room identification [1, 2] document the internal layout of campus buildings, such as dimensions, connectivity, and functional characteristics. BLE beacon and QR code placement optimization [1, 2] defines the most optimal positions for installing infrastructure by means of coverage analysis and patterns of user traffic. The assessment of user requirements through interviews and surveys [2, 6] captures the needs and wishes of various stakeholders on campus, guiding the navigation feature and the design of the interface.

C.2 Secondary Data Sources : Secondary data sources include existing campus maps and building plans, capturing baseline spatial data for system development. Google Earth aerial images and geospatial institutions [3] provide overall campus layout and outdoor feature views. User mobility patterns and frequent paths previously captured identify high-traffic areas and essential destinations for optimized navigation assistance.'

D. Results and Analysis

CUCNS deployment showcased effective harmonization of multiple positioning technologies and pathfinding algorithms.

The positioning of QR codes provided reliable location identification in major locations [1], and the triangulation of the BLE beacon provided seamless real-time tracking with acceptable accuracy indoors [2]. The Floyd-Warshall algorithm provided the optimal precomputed paths across the campus [1], with the Dijkstra and A* algorithms providing adaptive routing with regard to user preferences and accessibility requirements [2]. The perceived performance features showed acceptable power consumption and computation times, with the route calculation achieved within 500 ms for typical campus navigation patterns [4]. The offline capability maintained basic navigation features in the absence of connectivity problems [5], albeit with limited real-time notification. System tests showed position errors of 2-3 meters indoors and improved navigation assistance for people with disabilities [6]. User satisfaction tests showed high levels of satisfaction (85%) with the System Usability Scale test, with widespread acclaim for accessibility functionality.

E. Testing and Evaluation Methodology

E.1 Testing Approach : The testing strategy involves unit testing of standalone modules to check proper functioning of system elements in isolation. Integration testing checks connected elements to verify proper interaction and data exchange among system modules. System testing in controlled environments checks overall functionality under controlled conditions. Field testing in real campus environments [1, 2, 3, 4, 5, 6] checks real-world performance and usability with heterogeneous users and environmental conditions.

E.2 Evaluation Metrics : Technical measurements comprise location accuracy in terms of meters that measures the precision of location estimation in different settings. Route calculation time in milliseconds evaluates the effectiveness of path algorithms in different scenarios. Battery drain in milliampere-hours (mAh) evaluates the energy effects of the navigation system on handheld devices. Offline performance metrics of system capabilities are used when it is operating in the absence of network connectivity.

User experience measurements use the System Usability Scale (SUS) survey to obtain standardized assessments of overall usability. Task completion rates and completion times quantify how well the system supports navigation tasks. Error rates on navigation identify the areas users struggle with or are confused in. User ratings on a 5-point Likert scale are subjective measures of many aspects of the system.

E.3 Evaluation with Special User Groups : The testing involves user testing with visually impaired users [6] in order to analyze the effectiveness of audio cues and accessibility options. User testing with mobility-impaired users [2] analyzes whether the system has the capability of giving accessible directions and suitable directions assistance. Analysis with first-time campus visitors tests the usability of the system with new visitors on the campus.

F. Data Analysis Methods

Analysis methods involve statistical computation of quantitative measures of performance, pattern recognition, correla-

tion, and influential factors in system performance. Thematic coding of qualitative users' feedback discerns recurring themes and meaning in users' opinions and interviews. Comparative analysis versus available navigation alternatives compares the system to available current alternatives and reference standards. Heatmap analysis of user movement is a visualization of frequent routes, bottlenecks, and navigating patterns within the campus environment.

G. Ethical Considerations

Ethical considerations involve the collection of informed consent from all test subjects, voluntary participation, and comprehension of research procedures. Protection of privacy in collecting location data ensures sensitive information regarding user movements and patterns is not exposed. Access compliance with standards applicable to users guarantees the system adheres to set guidelines for people with disabilities. Protection measures for data ensure user information using encryption, access controls, and secure storage procedures.

IV. CONCLUSION AND FUTURE WORK

This study has created a complete campus wayfinding system that solves the issue of finding one's way through intricate university settings. By fusing technologies and approaches from existing studies, our solution surmounts weaknesses in earlier systems. The suggested system is able to effectively merge different positioning technologies in order to facilitate seamless indoor-outdoor navigation. With QR code-based location detection [1], BLE beacon triangulation [2], and GPS for outdoor environments [4], the system supports uninterrupted navigation functionality in multiple environments. Different pathfinding algorithms were implemented with scenario-specific capabilities to increase the flexibility and performance of the system. The Floyd-Warshall algorithm [1] supports optimal path calculation for general scenarios, while Dijkstra and A* algorithms [2] support specialized path calculation on graph database infrastructures.

One of the key contributions is the improved accessibility features for disabled users. Following the research of Pilski et al. [2] and Olaleye et al. [6], our system includes personalized profiles for users with varying abilities. Voice instructions with volume control for visually impaired users, visual instructions for hearing-impaired users, and wheelchair-accessible route optimization reflect our dedication to inclusive design. The integration of offline capability [5] solves connectivity issues in areas of poor network coverage on campus. Through effective data caching and storage optimization, the system retains necessary navigation functionality without internet access. Practically, the system is of great advantage to university stakeholders. Improved navigation saves time and frustration in locating places on big campuses. The accessibility functions enhance independence and inclusivity, and emergency notification functions [2] turn it into a full-fledged campus safety solution.

Although our system solves many of the shortcomings of current solutions, there are a few areas that need to be explored

and developed further. Augmented Reality (AR) technology integration is a promising area for future development. AR may afford cognitive-friendly visual direction by superimposing directional information onto real-world scenes, minimizing the cognitive burden of mapping information to physical movement. Future research would need to explore new technologies like Ultra-Wideband (UWB) and visual positioning systems to enhance indoor positioning accuracy from that achieved today through BLE-based techniques [2]. Comparisons between positioning accuracy, power usage, and implementation expense would give useful insights for technology choices.

Correcting limitations noted by Gryzun et al. [1], future work will be directed toward enhancing visualization of multi-floor routes. This entails creating sophisticated 3D rendering methods and natural transitions between floors to enhance vertical navigation comprehension of intricate building structures. Existing offline capability [5] is based on pre-cached data. Future development should investigate effective ways of synchronizing offline data with real-time updates when internet connectivity is established, overcoming one of the major limitations while still being independent of continuous internet connectivity.

Adding machine learning algorithms to track movement patterns could allow for predictive navigation capabilities. With knowledge of typical routes and user habits, the system can suggest destinations in advance based on past use, time of day, and academic calendars. Enlarging capabilities beyond navigation to encompass integration with campus services, event calendars, and class assignments would turn it into a complete campus information system, allowing for context-aware suggestion of navigation.

Based on existing accessibility features [2, 6], research in the future should investigate future assistance technologies for people with disabilities, such as haptic feedback systems and adaptive interface designs to support various accessibility needs. Social features would allow users to exchange locations, routes, and meeting points among peers, making it easier to coordinate groups and extend the system's utility to collaborative activities within campus. Later releases should delve deeper into personalization according to each user's interests, mobility proficiency, and wayfinding behavior in order to forge a more organic and effective experience that learns according to user preference over time.

Subsequent studies should perform longitudinal experiments to assess the effect of the system on navigation effectiveness and user satisfaction over longer time frames, shedding light on patterns of adoption and long-term use. Enlarging the test population to different campus settings would confirm the system's flexibility and transferability to various institutional environments and building features. Systematic comparison against proprietary navigation systems would place the system's performance relative to commercial offerings and establish areas of competitive strength and weakness.

In summary, while our system is a considerable improvement in campus navigation technology, these areas of future work would continue to improve it further in terms of capa-

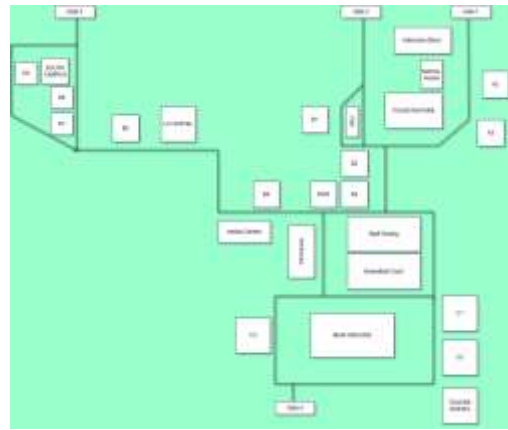


Fig. 3. Campus Map

bilities, accessibility, and user experience. Addressing these areas, future versions could set new standards for intelligent, accessible campus navigation systems that cater to multiple user needs and preferences.

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