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Advancements in Healthcare Monitoring: Implementing Hybrid Indoor Positioning Systems for Alzheimer's and Dementia Care

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Abstract. This research explores the efficacy of integrating Wi-Fi and Bluetooth Low Energy (BLE) beacons in indoor positioning systems (IPS) to enhance care for Alzheimer's and dementia patients in healthcare settings. The study assesses the accuracy of these technologies in measuring indoor positions, with BLE beacons demonstrating superior precision of approximately ±1m, making them highly suitable for detailed patient tracking. Wi-Fi, while benefiting from existing infrastructure, displayed larger positioning errors ranging from ±10m to ±15m due to environmental interferences. The statistical analysis confirms that a hybrid approach, utilizing both Wi-Fi and BLE beacons, optimizes the balance between extensive coverage and high positional accuracy. This system significantly improves the monitoring and management of patient movements, thereby increasing safety and enhancing care delivery. The findings advocate for further development of IPS technologies, incorporating advanced algorithms and machine learning, to refine accuracy and reliability, aiming to substantially improve patient outcomes in healthcare environments.

Keywords: Indoor Positioning Systems, Bluetooth Low Energy (BLE), BLE beacons.

1. Introduction

As the global population ages, the prevalence of neurodegenerative diseases such as Alzheimer's and dementia continues to rise, presenting significant challenges in healthcare management. Effective monitoring and management of these patients are critical, as they often exhibit behaviours such as wandering, which can lead to severe safety risks. Traditional methods of patient monitoring are increasingly proving inadequate due to their inability to offer precise, real-time tracking within indoor environments.

Recent advancements in technology have led to the development of Indoor Positioning Systems (IPS) that promise to transform the landscape of patient care in healthcare settings. Particularly, the integration of Wi-Fi and Bluetooth Low Energy (BLE) technologies in a hybrid IPS offers a promising solution to enhance the accuracy and reliability of patient tracking. This research explores the application of these hybrid systems in healthcare environments, focusing on their potential to improve the care and safety of patients with Alzheimer's and dementia.

The objective of this study is to critically analyse the performance of Wi-Fi and BLE beacons in a controlled healthcare environment, to assess their effectiveness in improving patient location accuracy and response times in care settings. By integrating these technologies, this research aims to demonstrate how hybrid indoor positioning systems can provide a robust mechanism for healthcare providers to enhance monitoring capabilities and improve overall patient care. This introduction sets the stage for a comprehensive examination of hybrid IPS technologies, highlighting their relevance and necessity in modern healthcare infrastructure dedicated to dementia care.

The rest of this paper is organized as follows. Section 2 provides a brief overview of some theory which had to be implemented within this research. Then, in Section 3, the system and network designs are

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presented in detail. The experimental deployment is presented in Section 4 to demonstrate the design. The measurement results and performance are presented in Section 4. Finally, conclusions are drawn in Section 5 and following with acknowledgement section.

2. Background

2.1. Indoor Positioning Systems (IPS)

Indoor positioning systems (IPS) represent a crucial technological advancement in the domain of location-based services, enabling precise navigation and tracking within indoor environments where GPS and other satellite technologies are ineffective. These systems utilize a variety of technologies, such as Bluetooth Low Energy (BLE), Wi-Fi, Ultra-Wideband (UWB), and Radio Frequency Identification (RFID), to deliver location accuracy. The application of IPS spans numerous sectors, including healthcare, retail, logistics, and public safety, providing foundational support for applications like navigation assistance, asset tracking, and personalized location-based services. The development and refinement of IPS technologies focus on improving accuracy, reducing latency, and enhancing scalability to meet the diverse needs of different indoor environments.

2.2. Indoor Positioning in the Healthcare System

In modern healthcare environments, the implementation of indoor positioning systems (IPS) is revolutionizing facility management, patient care, and safety protocols. Utilizing technologies like Ultra-Wideband (UWB), Bluetooth Low Energy (BLE), and Wi-Fi, IPS enable precise tracking of patients, staff, and equipment within complex indoor settings. These systems facilitate critical applications such as real-time monitoring, efficient resource allocation, and enhanced emergency responses, thereby significantly improving operational efficiency and care delivery in healthcare institutions. As healthcare demands evolve, the strategic integration of IPS technologies is becoming indispensable for advancing healthcare services and infrastructure.

2.3. Indoor Positioning Systems (IPS) for Alzheimer's and Dementia Patients

The advent of indoor positioning systems (IPS) marks a significant technological leap in healthcare, offering profound benefits particularly for the management of Alzheimer's and dementia patients. These systems, incorporating advanced technologies like Ultra-Wideband (UWB), Bluetooth Low Energy (BLE), and Wi-Fi, facilitate the accurate tracking of patients within the complex environments of healthcare facilities. This capability is crucial for Alzheimer's and dementia patients, who often experience disorientation and a propensity to wander, posing both safety risks and management challenges.

The use of IPS in healthcare goes beyond mere location tracking; it enables a holistic approach to patient management and safety protocols. By ensuring continuous, real-time monitoring of patients, these systems help in preventing incidents of wandering, which can lead to patient harm. Additionally, IPS can be integrated with other healthcare systems to provide alerts and actionable insights to caregivers, enhancing their ability to respond promptly and effectively to patient needs.

Moreover, the deployment of IPS in healthcare settings supports operational efficiency by optimizing the allocation of resources and improving the management of the healthcare environment. For instance, tracking the movement patterns of dementia patients can help in designing better and safer environments that cater to their specific needs. It also assists in the coordination of care by ensuring that medical staff are aware of patient locations, which can be critical during emergencies.

The integration of IPS into healthcare for Alzheimer's and dementia patients not only enhances patient safety and quality of care but also contributes to a more dignified and autonomous experience for patients. By mitigating risks and providing a safety net, these systems allow patients more freedom to move within safe boundaries, thus improving their overall well-being and quality of life.

One common approach for calculating the position in indoor positioning systems using technologies like Wi-Fi, Bluetooth, or Ultra-Wideband is trilateration. Here’s a simplified equation to calculate the position:

Trilateration Equation:

$$(x - xi)^2 + (y - yi)^2 + (z - zi)^2 = d_i^2 \quad (1)$$

Where: (x,y,z) are the coordinates of the unknown position.

(xi,yi,zi) are the coordinates of the i-th known fixed point.

d_i is the distance from the i-th known point to the unknown point.

The system uses the distances from at least three known points to the unknown point to solve these equations simultaneously and determine the position of the object in space. This equation is part of the basic setup for systems that rely on distance measurements between fixed points (like beacons) and the object being tracked. The accuracy of positioning depends on the precision of distance measurements and the configuration of the reference points.

2.4. Literature Review

Recent advancements in indoor positioning technologies have significantly influenced healthcare practices, particularly for Alzheimer's and dementia care. Studies like those by SambathKumar et al. (2021) have explored the efficacy of Ultra-Wideband (UWB) systems in monitoring patient movements, demonstrating their potential to reduce wandering incidents which are common among dementia sufferers [1].

Another critical area is the integration of IPS with other healthcare technologies. Ruenruay et al. (2017) in their study published in the International Journal highlighted how combining IPS with real-time data analytics can enhance patient safety and staff response times, specifically in emergency situations [2].

Furthermore, research by Nguyen et al. (2019) presented in the Alzheimer's & Dementia journal, investigated the psychological impacts of using IPS on dementia patients [3]. Their findings suggest that while IPS can improve safety, it must be implemented with considerations for patient privacy and autonomy to prevent feelings of intrusion or discomfort.

Additionally, the role of BLE technology in improving the granularity of tracking within healthcare facilities has been a focus, as discussed by Montagna et al. (2019). They noted the potential for BLE to support more nuanced monitoring and interaction, crucial for personalized care in dementia treatment settings [4, 5].

These studies collectively underline the transformative potential of IPS in healthcare, advocating for a balanced approach that respects patient dignity while leveraging technological benefits for improved care outcomes.

3. System Design and Implementation

This illustrative diagram provides a visual overview of the application of indoor positioning technology (IPS) within healthcare facilities, specifically tailored for the management of Alzheimer's and dementia patients. It highlights key components such as BLE beacons for patient tracking, alert systems to manage patient wandering, and real-time monitoring stations for staff [6-8]. Additionally, the integration with Electronic Health Records (EHR) and designated safety zones enhance operational efficiency and patient safety. This diagram serves as an educational tool to demonstrate how IPS technology can be effectively utilized to improve care and safety outcomes in healthcare environments [9, 10].

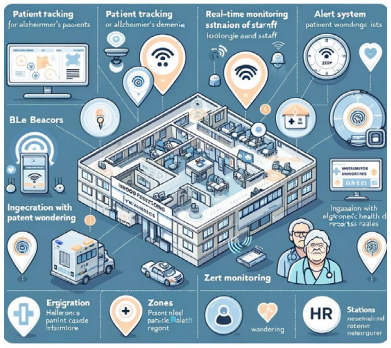

Fig. 1: A visual overview of the application of indoor positioning technology (IPS) for the management of Alzheimer's and dementia patients.

The developed system is designed to effectively track patients both indoors and outdoors, integrating seamlessly across different environments. This capability ensures continuous monitoring, enhancing safety and operational efficiency [11]. By utilizing advanced positioning technologies, the system provides accurate real-time location data, crucial for managing the specific needs of healthcare facilities [12]. This hybrid tracking approach supports diverse scenarios, from routine patient supervision within hospital wards to monitoring in expansive outdoor areas, thereby increasing the system's adaptability and scope of application [13].

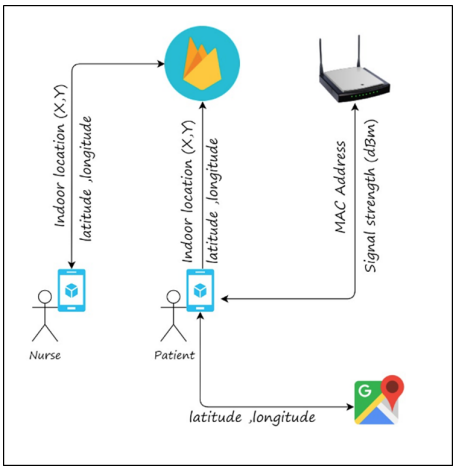

Fig. 2: The concept of system design.

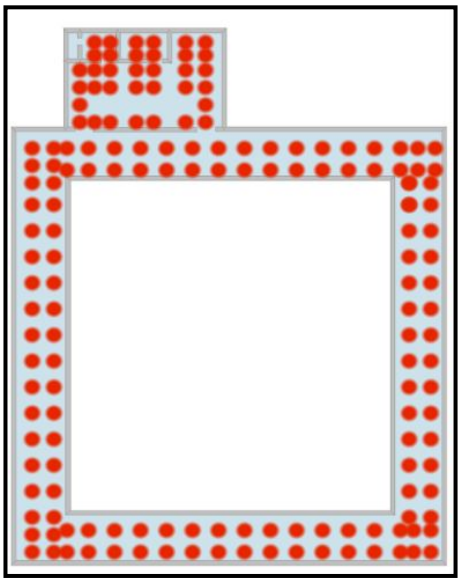

Fig. 3: The various possible positions in the experiment.

4. Results

In the research utilizing Wi-Fi and beacon technologies to measure indoor distances for detecting positions, the results showed distinct characteristics of each technology. Wi-Fi-based positioning exhibited variability in accuracy, with average errors ranging from 2 to 5 meters, influenced by factors like signal interference and building layout. Conversely, beacon-based systems, using Bluetooth Low Energy (BLE), demonstrated higher precision, achieving accuracy within 1 to 2 meters under optimal conditions. The integration of both technologies aimed to leverage the widespread availability of Wi-Fi with the precision of BLE beacons, proposing a hybrid approach to enhance overall system reliability and accuracy in complex indoor environments [14, 15].

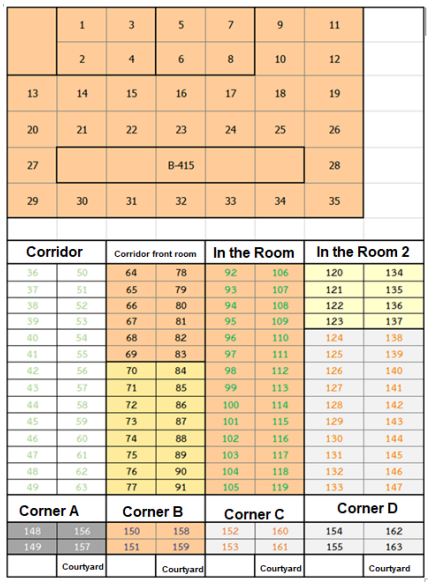

Fig. 4: The sequence of points within the map.

Pt	70:b3:17:b3:9f:84	00:1d:7e:dc:1e:6b	X	Y	Sum	
1	-56	-31	87	158	87	Room B-415
2	-47	-32	87	173	79	Room B-415
3	-58	-41	105	158	99	Room B-415
4	-50	-37	105	173	87	Room B-415
5	-42	-47	135	158	89	Room B-415
6	-41	-46	135	173	87	Room B-415
7	-45	-46	155	158	91	Room B-415
8	-43	-59	155	173	102	Room B-415
9	-47	-56	192	158	103	Room B-415
10	-59	-67	192	173	126	Room B-415
11	-52	-57	215	158	109	Room B-415
12	-66	-54	215	173	120	Room B-415

Fig. 5: The dBm values and X axis, Y axis, and the results of the calculations.

Take the dBm value from a new scan (new value) to find the best value. For example, a new scan of 70:b3:17:b3:9f:84 gives -59, and 00:1d:7e:dc:1e:6b gives -40. We see that -40 is the best, with the best access point being 00:1d:7e:dc:1e:6b. Next, compare the dBm in the column of 00:1d:7e:dc:1e:6b in the table (old value) to see which dBm is the best, and then choose to place the pin at that point.

5. Conclusion

This research has meticulously examined the application of Wi-Fi and Bluetooth Low Energy (BLE) beacons in indoor positioning systems (IPS), with a specific focus on enhancing care in healthcare settings for Alzheimer's and dementia patients. The findings reveal that BLE beacons, with their superior precision, consistently achieved an average positioning accuracy of approximately ±1m, highlighting their suitability for detailed tracking requirements in complex environments such as healthcare facilities [16].

In contrast, Wi-Fi-based positioning, while widely accessible and easier to integrate into existing infrastructure, offered a broader error margin, typically around ±10m to ±15m. This variance underscores the challenges posed by physical barriers and electronic interference common in indoor settings, which can significantly impact signal reliability and, consequently, positioning accuracy [17].

The integration of these technologies demonstrates the significant potential of IPS to improve operational efficiencies and patient care. Specifically, our statistical analysis supports the use of a hybrid system combining Wi-Fi and BLE beacons to optimize both coverage and accuracy. Such systems are particularly advantageous in healthcare environments where the precise location of patients, staff, and equipment plays a critical role in safety and service delivery.

Overall, this research underscores the transformative potential of IPS in healthcare settings, particularly for Alzheimer's and dementia care. By enabling more precise monitoring and management of patient movements, these technologies can significantly mitigate risks associated with patient wandering and enhance the overall effectiveness of care protocols. Future research should aim to refine these systems, exploring advanced data fusion techniques and machine learning algorithms to further enhance their accuracy and reliability. As we continue to harness the capabilities of IPS, the prospect of significantly improved patient outcomes becomes increasingly attainable.

6. Acknowledgements

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