A Convenient Mobile Application to Improve Healthcare Efficiency with Real-Time Wheelchair Tracking using Bluetooth Beacons

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ABSTRACT

In hospital settings, efficient wheelchair management is crucial for optimizing patient transport. Traditional methods, including manual tracking and GPS, often fall short because of indoor interference and high maintenance costs. This research presents a solution to this challenge utilizing bluetooth beacon technology to provide real-time localization of wheelchairs within hospital environments. By integrating bluetooth beacons with a centralized mobile application, our system offers precise and continuous updates on wheelchair availability and wheelchair location. This approach addresses common drawbacks of existing systems, such as the range limitation of the RFID system and infrared system, and the inaccuracy of GPS upon indoor use [1]. Through analysis and testing in simulated hospital conditions, the proposed system demonstrates significant improvements in efficiency, accuracy, and user experience. The results of the test suggest a cost-effective alternative for improving resource management and patient care in healthcare facilities.

KEYWORDS

Healthcare, Wheelchair, Real-Time Tracking

1. Introduction

The primary problem is the inefficient utilization and management of wheelchairs in hospital settings. Locating available wheelchairs can be time-consuming, which leads to delays in patient transport. Traditionally, hospitals manage wheelchairs manually, which often results in logistical challenges. As hospital environments become busier, the need for an efficient wheelchair tracking system has grown. Efficient wheelchair management is crucial for enhancing patient care as it reduces waiting times. During my time volunteering as a patient escort at Massachusetts General Hospital, I constantly encountered difficulties in locating available wheelchairs [2]. Especially on hot summer afternoons, when the hospital is bustling with discharged patients, the escorts face significant challenges, including difficulties locating unoccupied wheelchairs. Many escorts spent considerable time running around just to find an empty wheelchair rather than assisting the discharged patient and getting them out of the hospital as soon as possible. This inefficiency significantly stagnated the entire operation flow. When I was running between the buildings and up and down the stairs in search of wheelchairs, I wondered if there was an app that could display the real-time location of available wheelchairs, save human resources and energy while increase efficiency. This idea led me to explore the interconnection between wheelchairs, their locations, and the necessary technology to communicate these details to users [3]. Through research, I discovered digital solutions like Bluetooth beacons, which could be deployed on

David C. Wyld et al. (Eds): CMLA, CSEIT, NLPD, GRAPH-HOC, SPM, NeTCoM, NCS, ArIT, DMSE – 2025
pp.181 -191, 2025. CS & IT - CSCP 2025 DOI: 10.5121/csit.2025.151315

wheelchairs to continually signal their locations to a centralized device. Users, such as hospital staff and escorts, could be notified of wheelchair availability and location, which will transform wheelchair management into an efficient, streamlined process.

The RFID system aims at tracking and identifying objects using electromagnetic fields to communicate with tags. Its shortcomings are limited range and interference from metals and liquids, particularly in complex environments like hospitals. My project enhances range and accuracy using bluetoothbeacons and provides real-time updates. The methodology of radiofrequency and infrared signals is utilized for indoor navigation and object tracking by transmitting data wirelessly. However, this system requires a direct line of sight and is susceptible to light interference, and radiofrequency can face signal disruptions from electronic interference. By employing bluetooth beacons, my project improves on the line-of-sight issues and reliability through advanced signal reception techniques. Moreover, the GPS system provides precise global positioning and navigation outdoors by utilizing satellite signals. The shortcoming of a GPS system is that it is ineffective indoors due to weak satellite reception and high resource consumption [4]. My project offers effective indoor tracking, which overcomes GPS limitations with high indoor location accuracy and lower energy consumption.

Proposed solution: Real-time wheelchair tracking system using bluetooth beacons to monitor and display the location of available wheelchairs within the hospital.

Each wheelchair will have one bluetooth attached, and it will continuously transmit signals to places received in the hospital rooms. These receivers communicate with a centralized app that updates staff on the exact location and availability of wheelchairs. The app provides a live map, which allows escorts and staff to easily locate and retrieve wheelchairs to minimize time spent searching and optimizing patient transport logistics. This is an effective solution because the app offers real time updates on the availability of the wheelchairs, and it unburdens escorts from manual searches to enable them to focus on patient care. Also, faster wheelchair availability for patients leads to reduced waiting times and improved satisfaction. Unlike traditional methods, which are prone to manual labor and inefficiency, this solution automates the process and provides accurate information. Compared to GPS, which could only provide ambiguous locations indoors, bluetooth beacons offer precise indoor localization at a lower cost, and they are also convenient to carry. Therefore, this solution is both practical and scalable.

In these experiments, we evaluated the bluetooth beacon system's accuracy for wheelchair tracking in hospitals. The experiment results indicate that the tracking system is accurate with a consistent performance with a mean error of 0.20 meters. The second experiment assessed signal robustness under interference by positioning a bluetooth beacon near Wi-Fi routers, phones, and monitors. The results highlighted that Wi-Fi caused signal disruption. The distance of the signals, 1.99 to 2.02 meters, demonstrates a stable performance, but with Wi-Fi interference, distances varied up to 2.40 meters, which confirm signal interference. The sensitivity of bluetooth signals to radiofrequency disturbances accounts for the observed fluctuations, especially in areas with strong Wi-Fi signals. The findings confirm that the system is generally reliable, but it needs to address environmental challenges, particularly in managing strong radiofrequency interference for real-world applications.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Bluetooth beacons

One of the problems I had to consider when implementing the program is that Bluetooth beacons have limited battery lives. When the beacons are running out of battery, they must be replaced with new batteries in order for the system to operate. I came up with several strategies that can be implemented to minimize maintenance. First, utilizing low energy bluetooth models ensures reduced power consumption and offers longer operational periods without frequent battery replacements. Second, bluetooth beacons can be equipped with power management features, such as schedules transmission and adaptive power control to conserve energy. Additionally, utilizing rechargeable beacons can extend battery life and reduce costs. I used rechargeable beacons for my program, and with each bluetooth beacon, there is an equipped portable charger.

2.2. Signal interference

Another challenge I had to consider is signal interference. When deploying bluetooth beacon systems within hospital environments, various electronic devices and elements can disrupt or weaken bluetooth signals. Hospitals contain wireless infrastructure and medical equipment, all of which can cause electromagnetic interference, which leads to inconsistent beacon signaling. This interference can result in inaccurate location data, delayed updates, or even loss of signal. To address this, I could use strategies such as conducting detailed site surveys to identify areas prone to interference and adjusting receiver placement accordingly. Also, implementing frequency filtering techniques or utilizing multiple receivers can help rescue signal degradation. The method I chose is utilizing multiple receivers. I planned to use one receiver for each room on each floor of the hospital. By doing so, not only has it reduced signal disturbance, but users can also receive more accurate location information.

2.3. Tracking system

Problems related to integration with existing hospital systems are critical. Hospitals typically operate complex IT environments with electronic health record systems and various other clinical platforms. It is challenging to ensure that the tracking system is compatible with the existing digital systems. I could consider using standardized data formats to facilitate communication between the beacon system and hospital software. Collaboration with hospital IT staff would be vital to identify integration points and address potential problems, such as network security policies and data privacy regulations [5]. Moreover, I might consider leveraging hospital Wi-Fi or other wireless networks to support the system’s connectivity and to reduce the need for additional hardware. This integration would aim to minimize disruptions, ensure data consistency, and support adoption by hospital personnel.

3. SOLUTION

The main structure of my program is designed to facilitate real-time tracking and management of hospital wheelchairs by integrating hardware, software, and user interfaces. It links three major components: bluetooth beacons, attached to each wheelchair, gateway receivers installed in each room throughout the hospital, and a centralized mobile application used by staff. The flow begins with bluetooth beacons transmitting signals that represent each wheelchair’s unique ID label. These signals are received by the hospital’s receiver devices situated in each room, which relay the data to a central server. The server processes this data, updating the location of each wheelchair in real time. The mobile application connects to this server, which allows hospital staff and escorts to view an interactive map showing the current positions of available wheelchairs. When a staff member needs a wheelchair, they can check the app, locate the nearest empty wheelchair, and plan their route accordingly. Throughout the process, the system continuously updates the location as beacons signal their surroundings to ensure accurate tracking until the wheelchair is moved or used. To build this program, I used bluetooth beacon hardware, and Flutter, mobile development, for the user interface. The backend is supported by local servers like Firebase for real-time data management and synchronization [6]. This integrated structure allows for an efficient and reliable system for wheelchair management in the hospital from start to finish.

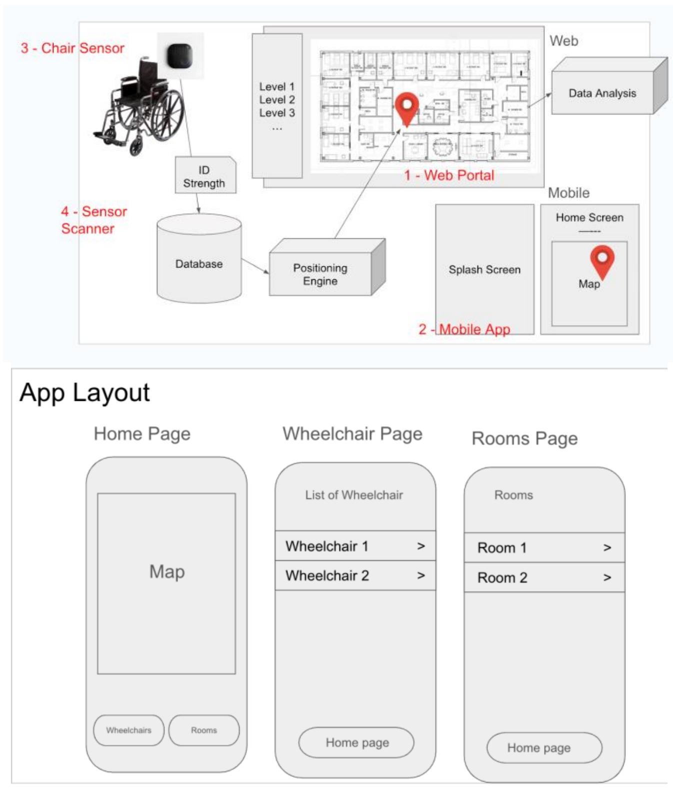

Figure 1. Overview of the solution

The centralized mobile application:
Purpose: The centralized mobile application serves as the user interface for staff to interact with the wheelchair tracking system. Its primary job is to receive the signals from the bluetooth beacons and gateway receivers and provide real-time information on the location and availability of wheelchairs to facilitate patient transport.

To implement the mobile application, I used Flutter to ensure the app works on both IOS and Android devices. The app connects backend services via Firebase, to manage user access and to process location updates [7]. Within the program, the mobile app functions as the endpoint of the system. It displays an interactive map of the hospital layout with the current positions of available wheelchairs. When a beacon signal updates the server with new location data, the app receives this information and refreshes the map in real time.

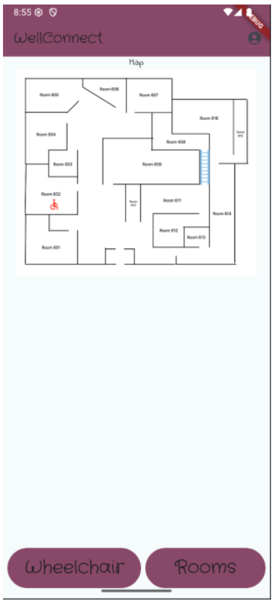

Figure 2. Screenshot of the map

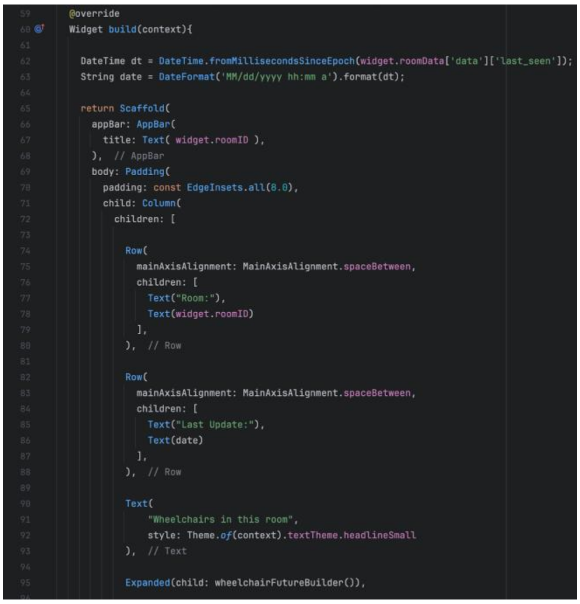

Figure 3. Screenshot of code 1

This part of the code begins by formatting the timestamp data into readable data using "DateTime" and "DateFormat". "Scaffold" provides a page layout including an app bar and a body [8]. Inside the body, padding and column layout organize the content vertically, with "Row" aligning information about room number, last update time, and the number of wheelchairs in the room, horizontally. "Expanded" makes sure that widgets can take up remaining space efficiently. Overall, this part shows current room status.

The purpose of a bluetooth beacon is to enable location-aware services by broadcasting signals that users' devices can detect. Implementation of bluetooth beacons relies on Bluetooth Low Energy protocols [9]. The key concept is proximity detection, which determines the location to trigger actions.

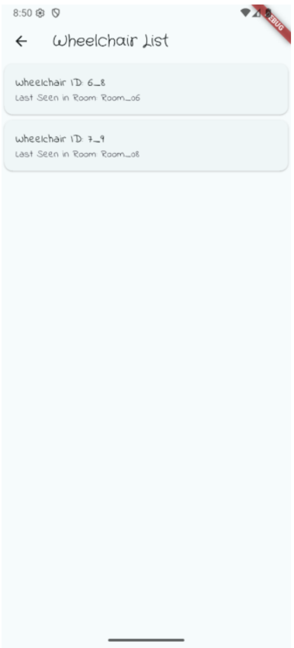

Figure 4. Screenshot of the list

```
class WheelchairListPage extends StatefulWidget {
  @override
  WheelchairListPageState createState()=> WheelchairListPageState();
}

class WheelchairListPageState extends State<WheelchairListPage> {

  Widget wheelchairListView(Map<String, List<dynamic>> wheelchairLocations) {
    print(wheelchairLocations);

    Map<String, String> wheelchairToRooms = Utilities.wheelchairToRoom(wheelchairLocations);
    List<String> wheelchairs = wheelchairToRooms.keys.toList();

    return ListView.builder(
      itemCount: wheelchairs.length,
      itemBuilder: (context, index) {
        String wheelchair = wheelchairs[index];
        return Card(
          child: ListTile(
            title: Text("Wheelchair ID: $wheelchair"),
            subtitle: Text("Last Seen in Room: ${wheelchairToRooms[wheelchair]}"),
          ), // ListTile
        ); // Card
      }
    ); // ListView.builder
  }
```

Figure 5. Screenshot of code 2

This code displays a list of wheelchairs and their status. The “WheelchairListPage” class manages the layout and display. Inside the “WheelchairListView” widget, it receives a map of wheelchair locations, processes it to generate a list of wheelchair IDs, and builds a list view. Each item in the list shows the wheelchair ID and the last seen location in the room. The structure of the code is to present real-time data clearly [10].

The purpose of receivers is to detect and interpret signals from bluetooth beacons for location services. Implementation uses Bluetooth Low Energy protocols. The concept involves signal detection and processing, in order for the system to identify beacons and trigger appropriate responses based on user location.

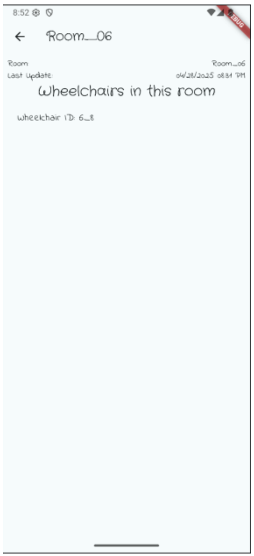

Figure 6. Screenshot of the room

```
Widget getWheelchairLocations() {
  return FutureBuilder(
    future: Utilities.findAllWheelchairs(),
    builder: (context, snapshot){
      if(snapshot.hasData) {
        if(snapshot.data != null) {
          return Expanded(child: wheelchairListView(snapshot.data!));
        }
        else {
          return Center(child: Text("Couldn't find any wheelchairs"),);
        }
      }
      return Center(child: CircularProgressIndicator(),);
    }
  ); // FutureBuilder
}

@override
Widget build(context) {
  return Scaffold(
    appBar: AppBar(
      title: Text("Wheelchair List"),
    ), // AppBar
    body: Column(
      mainAxisAlignment: MainAxisAlignment.center,
      children: [
        getWheelchairLocations(),
      ],
    ), // Column
  ); // Scaffold
}

}
```

Figure 7. Screenshot of code 3

This part of the code defines how the app builds the main screen for displaying a list of wheelchair locations. The “build” method returns a “Scaffold” widget, which provides the basic app structure[11]. The “Column” widget gets the current list of wheelchairs using the function “getWheelchairLocations”.

4. EXPERIMENT

4.1. Experiment 1

A possible blind spot is the accuracy of real-time wheelchair location updates, especially in environments with signal interference or connectivity issues. It is important that this part of the system works well because hospitals rely on precise and timely information. If the system inaccurately reports wheelchair locations, it could lead to delays and misallocation of wheelchairs.

To test the accuracy of the real-time wheelchair location system, I would set up an experiment in a controlled hospital environment that mimics hospital conditions. First, I would strategically place bluetooth beacons on one wheelchair and install one receiver in another room. I would start by manually recording the exact position of the wheelchair at various points. During the test, I would move the wheelchair to predetermined locations and intentionally introduce minor obstacles or electronic devices nearby to simulate potential signal interference. The system would record the wheelchair's position through the receiver and update the app accordingly. I would then compare the system's reported location against the manually recorded location to assess how accurately the system tracks the wheelchair.

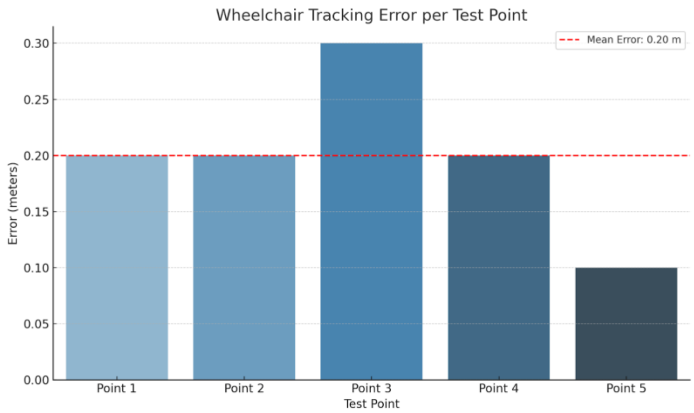

Figure 8. Figure of experiment 1

The analysis of the distance-based experiment revealed a mean error of approximately 0.20 meters and a median error of 0.20 meters, indicating consistent accuracy across tests. The smallest error recorded was 0.10 meters, while the largest was 0.30 meters. These results suggest that the Bluetooth beacon system provides highly reliable proximity measurements in indoor environments. The variation in error can likely be attributed to environmental noise, such as nearby electronic devices or structural barriers like walls or furniture. However, even the maximum deviation was small enough to be considered acceptable in real-world hospital use. The consistent performance across multiple test points also confirms that the system does not significantly degrade over longer distances within typical hospital room ranges. This reliability reinforces the system's value in optimizing wheelchair management, as staff can confidently act on the location data to retrieve equipment efficiently and with minimal search effort.

4.2. Experiment 2

A critical blind spot is how well the system performs in environments with high electronic interference, which is common in hospitals. Ensuring reliable tracking in such conditions is essential.

To evaluate signal robustness, I would conduct an experiment that places the wheelchair (with a Bluetooth beacon) at a fixed location while introducing various interference sources nearby—such as Wi-Fi routers, wireless phones, and medical monitors. I would log the beacon's distance as detected by the system every 10 seconds over a 5-minute period under normal conditions, then repeat the same with each interference source activated. I would compare the consistency and accuracy of signal readings between baseline and interference scenarios. This test simulates real-world hospital conditions where numerous electronic devices may distort Bluetooth signals and impact location reliability.

Condition	Detected Distance (m)
No Interference	2.0
No Interference	2.01
No Interference	2.02
No Interference	1.99
No Interference	2.0
Wi-Fi Router Nearby	2.3
Wi-Fi Router Nearby	2.25
Wi-Fi Router Nearby	2.1
Wi-Fi Router Nearby	2.4
Wi-Fi Router Nearby	2.35
Wireless Phone Nearby	2.05
Wireless Phone Nearby	2.0
Wireless Phone Nearby	2.1
Wireless Phone Nearby	2.15
Wireless Phone Nearby	2.05

Figure 9. Table of experiment 2

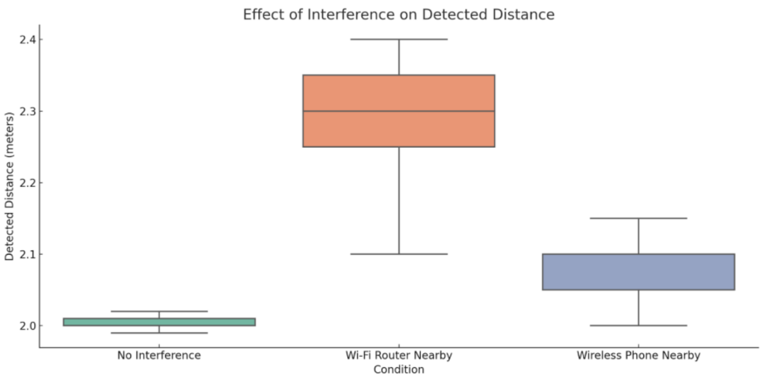

Figure 10. Figure of experiment 2

The experiment demonstrates clear variability in beacon signal accuracy depending on environmental conditions. Under no interference, the detected distance remained highly consistent, with all values tightly clustered between 1.99–2.02 meters. This indicates excellent baseline stability. However, when a Wi-Fi router was placed nearby, the signal fluctuated significantly, with detected distances ranging from 2.10 to 2.40 meters. This confirms that Wi-Fi equipment can cause substantial electromagnetic interference, leading to unreliable beacon readings. With a wireless phone nearby, there was some fluctuation, but it was far less pronounced, ranging from 2.00 to 2.15 meters. These results suggest that while the system is robust under typical conditions, it is vulnerable to strong radiofrequency noise. The greatest impact on signal quality came from proximity to powerful Wi-Fi devices.

5. RELATED WORK

The RFID system collects data by remotely distributing tags and transmitting them to readers, providing identification functions through non-contract communication [12]. The system provides medical staff with location information for medical devices to help staff to find medical items quickly and accurately. It is an effective solution because the system allows medical staff to immediately locate specific medical equipment and thus improve patient care quality. A limitation of RFID systems is limited read range and potential interference from metals or liquids, since they can affect signal accuracy and reliability. My wheelchair tracking system improves existing problems by providing more accurate and immediate location data. It integrates advanced sensors to increase reliability.

The tracking system using combined radiofrequency and infrared signals increase equipment utilization, increasing appropriate charge capture, and decreasing personnel time spent looking for equipment [13]. It is an effective solution because the system has great accuracy for equipment detection and location. However, since infrared signals require a clear line of sight to function effectively, obstacles like walls and furniture can disrupt the signal. Also, radio frequencies can face interference from other electronic devices within a hospital, which will affect location accuracy. Unlike systems that rely on less reliable technologies, bluetooth beacons provide continuous, real-time location updates. The use of bluetooth technology also enables easier integration with mobile apps and hospital infrastructure.

The tracking of medical equipment using GPS is the process of adding geographical identification to media as a geotagged photograph [14]. The data generated includes attitude and longitude coordinates. These tags are used to send location alerts to the server continuously so that the equipment can be tracked. Since this tracking technology uses GPS satellites to transmit signals, the signal strength is very strong, but it is very expensive, so it is recommended for only big-sized corporations. My project provides indoor location with more accuracy than GPS signals as they are only reliable outdoors due to poor satellite reception. Also, bluetooth beacons are generally less expensive to utilize and to maintain compared to the GPS system.

6. CONCLUSIONS

Some limitations include limited range and coverage, device compatibility, and data privacy and security. Hospital environments can have electronic interference and physical obstructions that may disrupt bluetoothbluetooth signals. Also, beacons have a finite effective range, so larger areas may require numerous receivers to ensure complete coverage, which will increase costs and complexity. The system relies on hospital staff to have mobile devices, which may vary in compatibility and signal reception quality, thus leading to inconsistent performance. Installing beacons and receives throughout the hospital involves costs and planning, which could be a barrier in some hospital settings [15]. Moreover, handling location data, especially in healthcare, requires strict protection to patient and staff privacy, which adds more complexity to system design. The converge limitation can be fixed by strategically implementing receivers to maximize range coverage, particularly in large or multi-floor settings. The data privacy problem can be mitigated by strengthening data encryption to protect sensitive location data to comply with healthcare privacy regulations.

In conclusion, my bluetooth based wheelchair localization system offers a promising solution to enhance efficiency, accuracy, and resource management within hospital settings [16]. While there are areas for improvement, such as signal reliability, security, and scalability, the foundation laid by this project demonstrates its potential to significantly increase the efficiency of wheelchair tracking and to improve patient care. With continued development, this system can become an important tool in creating smarter, more effective healthcare environments, which ultimately benefits both staff and patients.

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