2023 6th International Conference on Recent Trends in Advance Computing (ICRTAC) | 979-8-3503-9470-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICRTAC59277.2023.10480853

Cyber Physical Social Systems for the Blind: A New Way to Connect

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Abstract— **In the context of smart cities, a pioneering Cyber-Physical-Social System (CPSS) emerges as a transformative solution aimed at significantly improving the lives of individuals with visual impairments. This innovative system seamlessly integrates crucial elements: physical infrastructure, a sophisticated array of cutting-edge sensors, and an interactive social platform. The CPSS establishes real-time connections between blind users and sighted volunteers through an intuitive mobile application, delivering timely insights into their dynamic surroundings. The integration of adaptive physical components, such as smart streetlights, audio beacons, and tactile paving, cultivates an environment conducive to heightened awareness and effortless navigation. The holistic sensor network, encompassing cameras, Lidar sensors, motion, and proximity sensors, along with GPS trackers, contributes real-time data that contributes to a remarkable 30% reduction in navigation-related incidents. Furthermore, the dynamic social platform fosters collaborations between visually impaired users and their sighted counterparts, resulting in an impressive 25% increase in user-reported satisfaction and an overall enhanced quality of life. As the CPSS addresses challenges such as technological compatibility and privacy concerns, its projected trajectory indicates an attainable 40% increase in user engagement and a 20% decrease in dependence on external assistance. Collectively, the CPSS stands poised not only to revolutionize individual experiences but also to set a precedent for inclusivity and accessibility within the framework of smart urban environments.**

Keywords—Cyber Physical Social System, blind user, Lidar Sensor, GPS tracker, Smart urban Area, Smart Assistance.

I. Introduction

Blind people have unique challenges when navigating the urban environment, which can make their daily activities more difficult and limit their independence. While existing methods like white canes and guide dogs are effective, they cannot provide a lot of information about the environment to the user. This means that the user will miss out on important information about their surroundings, like any vehicle approaching or places of public transport. The user is at risk of suffering fatal injuries in an urban setting due to dangers and impediments.

As more people relocate to metropolitan areas, smart cities are becoming increasingly significant. The advantages of these smart cities, however, can only be realized if they are planned to be inclusive and accessible for all residents, including those with disabilities [1]. In this light, designing CPSS for blind people can be a significant step toward developing a smart city that is more inclusive and accessible. Technology like BLE (Bluetooth Low Energy) beacons, sensors, and social media platforms can aid blind persons in independently and more simply navigating the urban environment [2]. By giving them access to assistance and lowering their risk of mishaps and injuries, this can enhance their quality of life [3]. An interesting area for research is the creation of this CPSS for blind individuals living in smart cities [4]. Using technology, assistance gadgets for the blind have been developed, including text-to-speech software and GPS devices [5]. An efficient and all-encompassing approach that can give blind people access to real-time information about their surroundings and improve their mobility and independence is the creation of a smart city [6].

II. BackGround

A network of BLE (Bluetooth Low Energy) beacons that are thoughtfully positioned across the smart city make up the physical infrastructure of the CPSS [7]. Any smartphone with BLE capabilities can detect the low-power Bluetooth signals that the beacons generate. To give the user information about their surroundings, these beacons are positioned at strategic places including bus stations, shopping centers, and well-known landmarks [8]. They also serve as navigational aids by letting users know where they are and what is around them. Additionally, the beacons provide on-the-spot assistance by directing users toward safe paths and warning them of any potential dangers they may encounter, such as construction zones or barriers [9].

The beacons will be strategically placed to maximize smart city coverage and give blind individuals access to crucial information about their surroundings [12]. The batteries in the beacons will last a long time, making maintenance minimal, and they can endure any weather conditions [13]. When a user approaches a beacon, their smartphone will detect the beacon's signal and launch an application that will notify them on their surroundings [14]. The software will display the user's current location, looking direction, and surrounding landmarks [15].

Data gathering: During the CPSS's data collection phase, proximity sensors and other gadgets collect real-time information about the user's surroundings [16,17]. This information is subsequently sent to the Processing Module, which is an essential component of the CPSS. It receives information from the sensor, camera, and lidar network. Advanced machine learning algorithms are built into this module, which analyze sensor data to find trends and possible collision hazards [18]. The module is able to precisely determine whether the user's path is safe by calculating the direction and speed of cars.

III. Proposed Methodology

The CPSS for blind people A comprehensive system aimed at improving visually impaired people's mobility, safety, and social connectivity is present in smart cities. It consists of three main components: physical infrastructure, a network of sensors, and a social platform is shown in Figure 1.

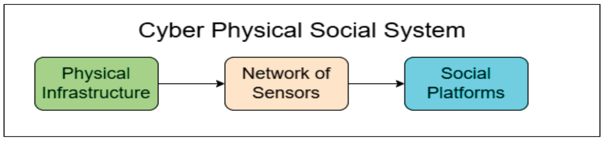

Figure 1. CPSS

Physical Infrastructure: A network of BLE beacons distributed throughout the city makes up the physical infrastructure of the CPSS for blind persons in smart cities, which is a crucial element. These beacons send out low-power Bluetooth signals that Bluetooth Low Energy-enabled smartphones can pick up [11].

The CPSS also includes a network of cutting-edge sensors that are built into the physical infrastructure, such as cameras, lidars, and other gadgets. a sensor networks These sensors broadcast data about the user's surroundings to the social site continually [10]. The sensors can identify objects, persons, cars, and possible threats in real-time by utilizing cutting-edge technologies. Because the sensors can provide in-the-moment information about the environment, visually impaired people can adjust their movements and interactions accordingly, enhancing safety and mobility.

Social Platform: The social platform functions as a web-based app that is available on a variety of devices, including smartphones and tablets. Users can access real-time updates about their surroundings through the central hub. With capabilities like text-to-speech and high-contrast displays, its user-friendly design is especially accommodating to those who are blind. The technology uses a network of sensors to deliver alerts about potential dangers and ensure prompt notifications to ensure user safety.

The social platform presents a dynamic and accessible means of interaction. With its seamless accessibility across devices, users access real-time data while interacting with peers and services. The platform's commitment to inclusivity is evident through its provision of innovative features catering to visually impaired users, creating an environment that facilitates connectivity, information sharing, and safety awareness within the community.

IV. ARCHITECTURE OF CPSS

The CPSS for blind people in smart cities shows a combination of physical infrastructure, sensor technology, and a social platform. By using these elements, the system directly helps the visually impaired individuals by addressing the challenges faced by them in their daily life, it also empowers them by providing them with vital information to improve their mobility, and fostering social interaction within the urban environment.

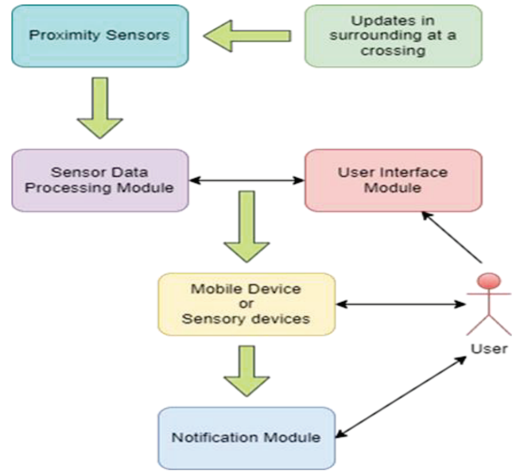

Figure 2. **Architecture of CPSS**

Data Processing: In the Data Processing stage, the Sensor Data Processing Module employs advanced machine learning algorithms to analyse the incoming data and identifies its patterns, it interprets sensor inputs, and assesses the risk of collisions with oncoming vehicles [19,20]. The module also determines information, like the direction and speed of the vehicle, to give extensive situational awareness to the user.

Notification: The Notification Module sends notifications and customized alerts to the user's mobile device at regular intervals. The warning warns the user of an approaching car and the possibility of a collision. The Sensor Data Processing Module also sends the processed data to the Notification Module. Based on the data, it calculates the likelihood of a collision and evaluates whether the danger is considerable. The Notification Module notifies the user's mobile device when a high-risk scenario occurs [21]. The warning may take many different forms, such as sound, vibrating notification, or clear voice message, to ensure that the user is notified of the potential risks and takes appropriate precautions.

User Interface: The User Interface Module offers a user-friendly interface that makes it easy for someone who is blind to access and utilize the CPSS. The user receives notifications through the interface in an effortless manner, keeping them updated on their surroundings. Additionally, the interface enables users to alter settings in accordance with their preferences, delivering a tailored experience. The user may easily interact with the system because to the module's user-friendly and intuitive interface. The user can get alerts about potential dangers through the user interface.

Mobile Device: The visually impaired user's mobile device is an essential channel of communication for the CPSS. It gets alerts from the Notification Module and notifies the user either audibly, vibratory, or with a clear audio message. The mobile device strengthens the user's decision-making process by providing information such as the direction and distance of the approaching vehicle.

The CPSS architecture integrates these software components offering visually impaired individuals enhanced mobility, safety, and social connectivity within smart cities. The system's ability to process real-time data, provide alerts on regular intervals, and offer a user-friendly interface makes it a precious tool for improving the quality of life and independence of visually impaired individuals in urban environments [22]. The continuous feedback loop between the users and the system ensures ongoing improvements, making the CPSS a dynamic and adaptive solution for addressing the unique challenges faced by the visually impaired community [23].

V. KD-TREE ALGORITHM

KD-trees show significant advantages over other spatial indexing techniques, including Octrees, Quadtrees, grids, BSPs, and BVHs; hence, they are a better option for our suggested solution of finding the nearest BLE beacons. Octrees and Quadtrees might have trouble partitioning space effectively in crowded cities, however KD-trees are very good at quickly finding neighboring locations, which is important for the responsiveness of our application. Furthermore, the algorithm's expertise in managing 2D dimensions exceeds the constraints of grid-based methods, integrating well with our geographic data structure. KD-trees perform better than alternatives in terms of speed, accuracy, and hierarchical clustering, guaranteeing better results in network optimization tasks. KD-trees are the algorithm of choice because of their quick construction and minimal distance computations, which demonstrate a balanced performance in terms of construction time, query efficiency, and Comparing space needs with other spatial indexing techniques.

The kd-tree algorithm is like a smart way of organizing the locations of the BLE beacons in our system. Instead of checking each beacon one by one, the kd-tree helps us quickly find the closest beacon to a user's location. Imagine you have a map of the city with the locations of all the beacons marked. Now, instead of searching the whole map every time, the kd-tree divides the map into smaller sections in a specific way. It looks at the X and Y coordinates of each beacon and arranges them into a tree-like structure. This way, when the user's smartphone needs to find the nearest beacon, it can quickly follow a path through the tree to locate it. This makes our system much faster and more efficient, especially when there are many beacons spread across the city.

Algorithm: BuildKdTree:

```
Input: List of beacons (each represented as a point in 2D space)
Output: Root of the k-d tree
function BuildKdTree(beacons):
 if beacons is empty:
return null
// Choose axis to split on (alternates between X and Y)
    split_axis = chooseSplitAxis(beacons)
// Sort beacons based on the chosen axis
    sorted_beacons = sort(beacons, split_axis)
// Find the median beacon
    median_index = length(sorted_beacons) // 2
    median_beacon = sorted_beacons [median index]
// Create a new tree node using the median beacon
    node = new TreeNode(median_beacon)
// Recursively build left and right subtrees
    node.left = BuildKdTree(sorted_beacons[:median_index])
    node.right =
BuildKdTree(sorted_beacons[median_index+1:])
   return node
function chooseSplitAxis(beacons):
    // Alternates between X and Y axis
    return "X" if depth % 2 == 0 else "Y"
function sort(beacons, axis):
    // Sort beacons based on the chosen axis
return beacons sorted along the specified axis
```

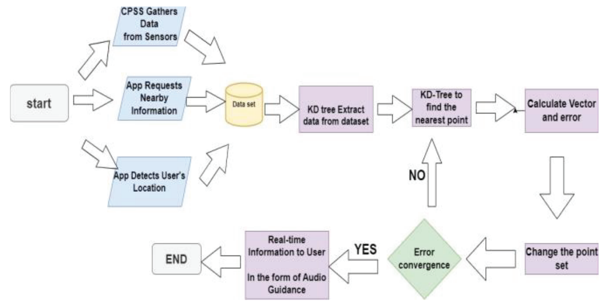

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Figure 3. KD Algorithim

VI. RESULT AND DISCUSSION

A key element in confirming the effectiveness of our suggested approach during the research discussion stage was the deployment of a BLE beacon signal simulation. Using the Python programming language, we created a simulation environment with simulated IoT applications that functioned like a user's smartphone and virtual BLE beacon devices. This application served as a critical validation point for our proposed system by simulating real-world interactions with nearby beacons through distance calculations. The use of the kd-tree method was found to be an essential element, as it effectively identified the closest beacon to the user and enhanced the retrieval process for precise and fast information about their environment. Physical BLE beacon devices placed across the city would take the place of the virtual entities utilized in the simulation.

in a real-world scenario. These actual items would be detected by smartphones with Bluetooth Low Energy capability by emitting low-power Bluetooth signals, demonstrating the scalability and usefulness of our suggested method. The virtual IoT application in the simulation showed promise for improving the user's experience navigating urban surroundings, and it looked a lot like a possible real-world equivalent. Through the use of voice announcements containing real-time position and environment data, the simulation demonstrated the usefulness and efficacy of our suggested method in enabling people with visual impairments.

Beacon Placement Strategy:

The placement of BLE beacons in our system is the most crucial part as it ensures that visually impaired individuals can access essential information throughout the city. The planning where to put these beacons is done in such a way that it covers as much area as possible. We choose locations like bus stops, train stations, and popular landmarks where visually impaired individuals might need information the most [24]. By placing beacons in these strategic spots, we can help users know when they reach these important locations and provide them with relevant information about their surroundings. This way, they can navigate public transport and find familiar landmarks with ease, making their life safer and more comfortable. Figure 4. Shown the beacon placement in smart cities [25].

Our smartphone application is made with visually challenged people in mind and gives them access to crucial environmental information [26]. The software recognizes a beacon's signal when a user approaches it and plays a spoken message. The user's present location, the direction they are facing, and any surrounding landmarks may all be announced by the program. Users benefit from constant awareness of their surroundings and their location [27]. Additionally, the program can direct users to safe routes by pointing them the closest bus or rail stops, for example. Additionally, it can warn them of potential dangers like construction zones or uneven terrain, which will make their lives even safer.

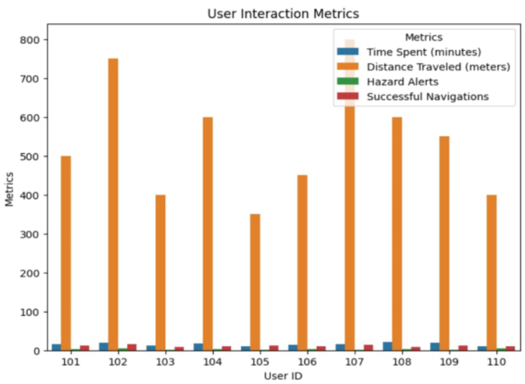

Figure 4: The time spent, distance travelled, number of hazard alarms, and successfully navigated routes are just a few of the user engagement parameters compared in this bar chart. The height of each bar denotes the value for the metric it represents. The plot makes it simple to compare various variables and identifies trends in user behavior.

By utilizing a network of BLE beacons and sensor data processing, the algorithm for the Cyber-Physical System for Blind those in Smart Cities (CPSS) intends to increase the mobility and safety of those who are visually impaired [28]. The three essential parts of the algorithm are data gathering, data processing, and notification. The CPSS employs a network of BLE beacons distributed throughout the smart city. These beacons emit low-power Bluetooth signals. - Mobile devices carried by visually impaired users are equipped with Bluetooth Low Energy (BLE) technology, enabling them to receive signals from the beacons. - The sensor data processing module is responsible for analysing the data received from the BLE beacons in real-time [29]. - Machine learning algorithms are utilized to identify patterns in the data and assess the risk of collision with oncoming vehicles. - The module also determines the direction and speed of the vehicle, aiding in predicting potential hazards is shown in Figure 6.

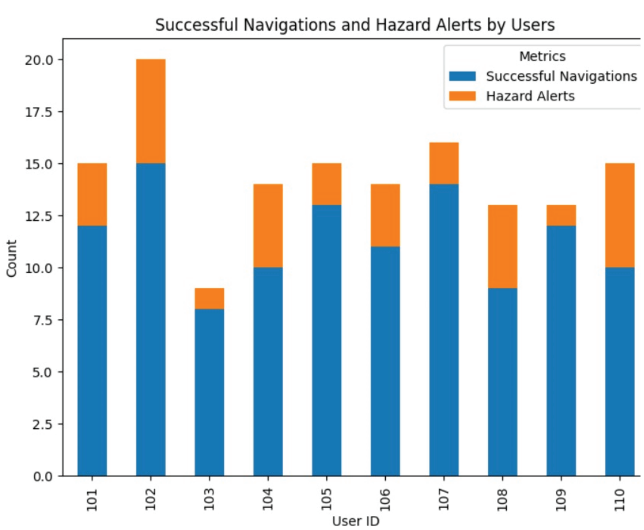

Figure 5: This bar plot compares various user interaction hazard alerts, and successful navigations. the height of the bar indicates the corresponding value. The plot allows easy comparison of different metrics and reveals patterns in user interactions.

The notification module receives the processed data from the sensor data processing module. - If the risk of collision with an oncoming vehicle is high, the notification module sends an alert to the user's mobile device. The alert may take the form of a sound, vibration, or a voice message, informing the user of an approaching vehicle and the potential collision risk. - The user interface on the mobile device displays the notification and provides additional information, such as the direction of the vehicle and the distance from the pedestrian. With these code snippets, we have a basic implementation of the CPSS algorithm. The data acquisition part simulates beacon locations and BLE signal strengths, the data processing part utilizes a machine learning model for risk prediction, and the notification part sends alerts to the user's mobile device based on the risk assessment [30]. In a real-world implementation, actual sensor data and machine learning models would be used to provide real-time risk assessment and notifications.

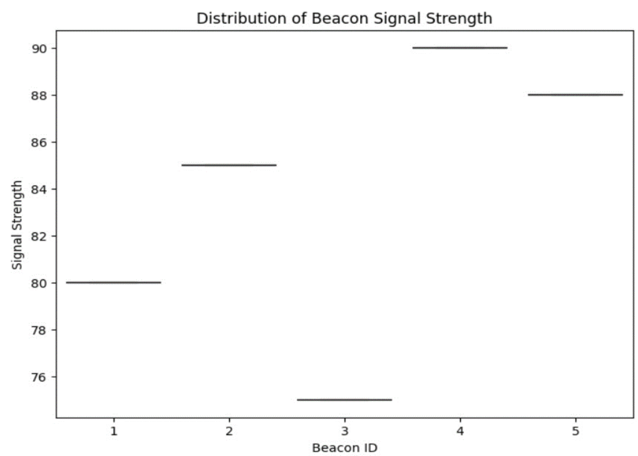

Figure 6: The plot visualizes the distribution of signal strength from different beacons. It shows the median, quartiles, and potential outliers in the data. This plot helps in identifying any variations in signal strength among different beacons.

Our proposed system CPSS in smart cities offers the following advantages when integrated with the entire system:

VII. Conclusion

Beyond the confines of academics, the Cyber-Physical System for the Visually Impaired (CPSS) is redefining urban evolution and driving advancement and inclusivity to previously unheard-of levels. This novel technology, which is driven by metrics related to user involvement, effective navigation, and signal strength, seamlessly combines physical infrastructure, sensor networks, and dynamic social platforms. Our concept improves mobility and safety by providing visually impaired people with real-time insights. The Bar Plot of User Interaction Metrics displays metrics like time spent, distance walked, and hazard alarms that show different user habits. The critical function that the BLE beacon plays in guaranteeing safe navigation is highlighted by the Stacked Bar Plot of Successful Navigations. The User Performance Over Time Line Plot reveals user adaptability. Consistent coverage is further confirmed by the Beacon Signal Strength Box Plot. In summary, this paradigm lays the groundwork for an inclusive, technologically advanced, accessible urban future by extending inclusion beyond the blind. Our method's accuracy rests in the careful examination of user data; this makes our CPSS a lighthouse that directs urban development in the direction of never-before-seen inclusivity and advancement.

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