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Enhancing Dementia Patient Tracking: A Comparative Study of RFID-Based Detection Systems Using Parked and Moving Vehicles

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Abstract: Dementia, a progressive neurological disorder affecting millions globally, poses significant challenges in patient care, particularly due to the risk of wandering. Traditional tracking systems like GPS, Bluetooth, and Wi-Fi often fail to provide reliable, real-time tracking, especially in dense urban environments or areas with poor signal coverage. This paper proposes an innovative RFID (Radio-Frequency Identification)-based tracking system that leverages moving vehicles to enhance the detection and localization of wandering dementia patients by providing a robust, scalable solution for both urban and suburban environments. Unlike existing systems that rely on parked vehicles [7], our approach utilizes a network of moving vehicles equipped with RFID readers, significantly expanding detection coverage and reducing blind spots. We conduct a comparative analysis between the proposed moving vehicle-based system and the existing parked vehicle-based system, using real-world data from Punjabi University, Patiala, and simulations via SUMO (Simulation of Urban MObility). Our results demonstrate that the moving vehicle-based system improves average detection times by up to 60% when the sampling rate is always ON, reduces failed detection rates by 50%, and enhances overall system reliability. The study also addresses technical, privacy, and health-related challenges, offering solutions to optimize system performance.

Keywords: *Dementia, Detection systems, GPS, Parked vehicles, Moving vehicles, RFID, SUMO.*

1. Introduction

Dementia significantly impacts patients' cognitive functions, memory, and ability to perform daily activities. One of the most challenging aspects of dementia care is managing patients who are prone to wandering, a behavior that poses serious risks to their safety and well-being [1]. According to the World Health Organization (WHO), over 55 million people globally live with dementia, and this number is expected to triple by 2050 [2]. This alarming trend underscores the urgent need for effective solutions to enhance the safety and quality of life for dementia patients.

Conventional tracking technology, including GPS, Bluetooth, Wi-Fi, and RFID, can be employed to monitor patients with dementia. [3]. However, these technologies have some limitations in providing reliable and real-time tracking, particularly in dense urban environments or areas with poor signal coverage [4]. For instance, GPS-based systems are ineffective indoors, while Bluetooth and Wi-Fi tracking solutions suffer from limited range and high-power consumption [5]. These limitations highlight the necessity for innovative and robust tracking solutions that can operate seamlessly across diverse environments.

Among these, RFID technology has gained significant attention due to its cost-effectiveness, passive tracking capability, and integration potential with urban infrastructure [6]. Recent advancements in RFID technology have expanded its applications in healthcare, including asset tracking, patient monitoring, and inventory management [7]. RFID systems consist of tags attached to the patient and readers that detect these tags within a specific range. However, its potential for dementia patient tracking, particularly in dynamic scenarios involving moving vehicles, remains underexplored.

A remarkable study by Griggs et al. [7] introduced an RFID-based tracking system utilize parked vehicles which are equipped with RFID readers in urban environments to scan for missing individuals. While effective in areas with high vehicle density, its reliance on parked vehicles introduces critical limitations. In locations with low parking availability, fewer vehicles, or restricted parking zones, detection gaps occur, leading to significant blind spots in patient tracking [8].

To address these limitations, we propose an enhanced RFID-based tracking system utilizing moving vehicles. By equipping public transport, taxis, and other regularly moving vehicles with RFID readers, we can significantly expand detection coverage, ensuring real-time tracking regardless of parking availability [9]. This dynamic approach enhances detection rates, reduces failure to detect, and improves overall system reliability in urban and suburban environments [10].

This study aims to address this gap by proposing an RFID-based detection system that leverages moving vehicles as a service delivery platform. It is structured as follows and

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illustrated in the figure 1.

1.1. Network of Participating Moving Vehicles:

A network of moving vehicles, such as ambulances, cars, or public vehicles, is equipped with RFID readers and antennas. These vehicles communicate with an administrative center via broadcasting and receiving stations.

1.2. Missing Entity with RFID Tag:

The dementia patient carries a passive RFID tag, embedded in a wristband or other wearable device. The tag operates without a battery, drawing power from the RFID reader's electromagnetic field.

1.3. Alert Source and Administrative Centre:

When a caregiver or family member reports a missing patient, the administrative center (e.g., police or healthcare providers) receives an alert. The center then activates the RFID-based application on participating moving vehicles.

1.4. Detection and Reporting:

As moving vehicles traverse the area, RFID readers continuously scan for the unique RFID tag carried by the missing individual. Upon detection, the vehicle transmits information such as the timestamp of detection, GPS location of the detecting vehicle, Unique RFID tag ID of the patient. This information enables the administrative center to determine the last known location of the missing entity.

1.5. Localization and Recovery:

Once the patient is detected, the administrative center initiates a response procedure. Law enforcement or emergency personnel can be dispatched to the last known location to refine the localization process and assist the patient.

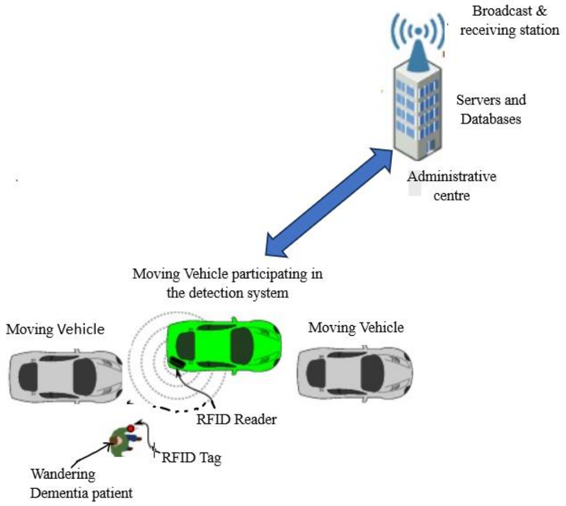

Fig. 1. An Illustration of Detection System

To assess the effectiveness of our system, we conduct a use case analysis involving a missing Alzheimer's patient. Validation is performed using real-world parking data from Punjabi University, Patiala, to evaluate system performance. A major challenge is accurately simulating a large-scale, real-world environment. To address this, we employ the SUMO (Simulation of Urban MObility) software, which allows for the emulation of hundreds or thousands of vehicles participating in the detection service, while simulated pedestrians navigate random paths [11].

The remainder of this paper is structured as follows: Section 2 reviews existing RFID-based tracking solutions, their limitations, and the need of proposing system. Section 3 presents the detailed system architecture and methodology used for both detection systems. Section 4 provides experimental results and a comparative analysis of the two approaches. Section 5 discusses implementation challenges and future enhancements, followed by conclusions in Section 6.

2. Related Work

Wandering is a common and dangerous behavior among individuals with dementia, particularly those with Alzheimer's disease [12]-[19]. While walking can provide physical and psychological benefits, it also poses significant risks, such as patients wandering away from safe areas and becoming disoriented or falling, experiencing emotional distress, or being exposed to harsh weather conditions [20]. Patients may leave their homes at night, inadequately dressed, increasing the risk of injury or hypothermia. The Alzheimer's Society [21] has two main types of devices to mitigate these risks:

2.1. Alarm systems:

These alert caregivers when a patient moves beyond a predefined boundary (e.g., leaving the front garden). However, these systems do not provide real-time tracking.

2.2. Tracking Devices

These use technologies like GPS or mobile networks to monitor the patient's location in real-time [22]. Examples include wearable devices [23] like shoes [25], watches, pendants, and smartphone applications [24]. These devices often include panic buttons for patients to signal when they are lost or in distress.

While tracking devices are useful, they have several limitations. Like, many tracking devices require frequent charging, which can be inconvenient for patients and caregivers. GPS-based devices struggle indoors or in areas with poor satellite coverage, while Bluetooth and Wi-Fi devices have limited range and continuous tracking raises ethical and privacy issues [26], as patients may feel their autonomy is compromised. Some devices may be too complex for elderly patients to operate effectively. RFID technology has emerged as a promising alternative for tracking individuals [27]-[29], particularly in healthcare settings. In this paper, we do not go into detail about the ethical concerns related to tracking people or the technical aspects of security in location monitoring systems. However, we recognize that these are crucial issues that should not be overlooked.

The proposed system in this paper addresses these gaps and any data transmitted between moving vehicles and the administrative center during a missing person detection event must be securely handled. To ensure privacy and data integrity, encryption techniques should be applied, preventing unauthorized access by hackers or even the vehicle owners themselves. This ensures that no external entity can intercept or identify that a detection has occurred.

In general, the Alzheimer's Society [20] emphasizes several key considerations when selecting a tracking device for dementia patients:

Battery Life: How frequently does the device require recharging?

Coverage and Signal Strength: Will the system function effectively in indoor and outdoor environments? Are there areas with weak or no signal?

Ease of Use: Is the device simple and intuitive for both patients and caregivers?

Response Mechanism: What steps should be taken when the system detects a missing individual or triggers an alert?

These factors are fundamental in the design and implementation of our proposed system. Before describing our approach, we first review existing solutions for locating missing individuals, particularly those designed for people in need.

MedicAlert® + Alzheimer's Association's Safe Return®: This system [31] relies on a community support network, including local Alzheimer's Association chapters and law enforcement agencies. When a patient goes missing, caregivers can report it to the network, and if the patient is found, their MedicAlert® ID jewellery can be used to reunite them with their caregivers.

Indoor tracking systems: The Escort system, as described in [17], involves patients wearing mesh-networked badges that transmit real-time indoor location data. This system relies on a Talking Lights optical location setup, which uses standard light fixtures and other light sources as location beacons. When a patient is identified as being at risk, the system sends immediate alerts via pagers or SMS to caregivers [30]. In [33], a Smart Hospital System (SHS) was developed to automate the identification and tracking of both patients and medical equipment within hospitals. This system integrates RFID, Wireless sensor networks, and smart mobile technologies, all connected through a Constrained Application Protocol (CoAP)/IPv6 over Low-Power Wireless Personal Area Network (6LoWPAN)/REST infrastructure. The SHS gathers real-time data on environmental conditions and patients' physiological parameters using a hybrid sensing network composed of 6LoWPAN nodes with UHF RFID capabilities. The collected data is sent to a central control system, where it is made accessible to both local and remote users through a REST web service.

Electronic tagging systems: Another approach, explored in [32], involves an electronic tagging system adapted from prisoner monitoring technologies. In this system, elderly dementia patients wear bracelets equipped with small radio transmitters. Monitoring stations detect signals from these bracelets, confirming the patient's presence in specific zones. Similarly, [34] presents an RFID-based patient tracking and mobile alert system designed to improve patient safety and comfort in hospitals by integrating information and communication technologies.

RFID-based Parked vehicle system for detection: A notable study by Griggs et al. introduced an RFID-based tracking system using parked vehicles, where vehicles equipped with RFID readers detect missing dementia patients wearing RFID tags [7]. This approach is innovative as it leverages existing parked vehicles in urban environments rather than relying on fixed RFID infrastructure. However, this method has major drawbacks: such as, this system is limited to areas with high vehicle density so it cannot be used in suburban or rural regions. When there is no parked vehicle, it is ineffective. Another limitation of this system is delayed response time.

These challenges create critical blind spots in real-time patient tracking, motivating the need for a more dynamic system.

3. System Design and Methodology

The proposed system in this paper is most likely to the system that use parked vehicles' network to detect the missing entities [7] and shares certain features with the MedicAlert® + Safe Return® system [31], but incorporates automation to improve tracking efficiency. In this approach, when a caregiver contacts an administrative center, such as a law enforcement agency, to report a missing dementia patient, a tracking application is activated within a network of moving vehicles.

This network covers a large geographical area, assuming that the missing person is still nearby. Each participating vehicle is equipped with an RFID reader and antenna, allowing it to scan for RFID tags worn by missing individuals. The person is expected to be wearing a medical accessory, such as a wristband or pendant, embedded with a passive RFID tag. As the individual moves through different locations, any moving vehicle within range can detect the RFID signal and send the details to the administrative center which contains: a unique RFID tag ID assigned to the individual, timestamp of detection, and GPS coordinates of the detecting vehicle.

If the patient continues to wander, additional vehicles in the network will track them and keep updating the administrative center. This process continues until law enforcement or emergency responders arrive at the last recorded location and help the missing individual to return safely. The complete details about the RFID technology are given below:

RFID [35], [36] is a technology that uses radio waves to automatically identify objects or individuals. While there are multiple identification methods, the most common approach involves storing a unique serial number on a microchip connected to an antenna. This combination, known as an RFID transponder or tag, allows the antenna to transmit data to an RFID reader. The reader emits electromagnetic waves, which are then reflected by a passive RFID tag and converted into digital information that can be processed by a computer.

RFID tags are categorized into three primary categories: Active tags which are equipped with a battery for extended communication range, Semi-passive tags which are partially powered by a battery but still reliant on the reader’s energy and passive tags that do not have a battery and draw power from the electromagnetic field of the reader. Since passive RFID tags do not require an internal power source, they can be small, lightweight, and maintenance-free [37]. In the context of our proposed system, these tags can be embedded into wearable accessories such as bracelets or pendants, allowing individuals to be tracked efficiently without the need for frequent recharging [38]. Unlike barcodes, RFID tags do not require direct line-of-sight scanning, making them ideal for placement inside vehicles equipped with RFID readers.

RFID readers can capture thousands of tag IDs per second, ensuring rapid and reliable identification [39]. However, deploying multiple RFID readers in proximity, such as within a network of moving vehicles, can lead to radio frequency interference and increased power consumption. To optimize energy use, controlled polling intervals are used instead of continuous scanning. While scheduled reads help to conserve battery life, they may slightly reduce detection rates if a tag passes by when the reader is inactive.

The range of passive RFID tags can vary from a few centimeters to approximately 12 meters under normal conditions. However, high-performance UHF passive tags can extend detection distances to 35 meters with fixed readers [40]. In practice, factors such as antenna positioning, tag orientation, cable length, and environmental interference (e.g., signal reflection from water or competing radio frequencies) affect real-world read range [41].

In our study, we evaluate the performance of a moving vehicle-based RFID detection system by modifying parameters such as polling rate of RFID readers (Always ON, polling rate=0.2Hz), detection range (4m,8m,12m,16m) and number of participating vehicles equipped with RFID readers (10-100%). The results will analyze average detection times, detection accuracy, and failed detection rates, helping to assess the effectiveness of our system in real-world conditions.

4. Performance and Evaluation Results

To evaluate the effectiveness of our proposed system, we conducted experiments using road vehicle networks and pedestrian walkways within the Punjabi University, located in Patiala, India [49]. This region, situated outside of Patiala city, has a proper parking area and moving vehicles throughout the university, making it a suitable test area for our study for the comparison of parked and moving vehicle-based detection systems. For our dataset, we included only parking spaces that are present in the university, no parking area or road area is considered under the research analysis. One of the key objectives of this study was to vary the percentage of participating vehicles in the RFID-based detection network to assess its impact on tracking accuracy and performance comparison of both systems.

The proposed system was simulated using SUMO [11], a widely used open-source tool for microscopic traffic modeling, developed by the German Aerospace Centre (DLR) [51]. SUMO is capable of handling large-scale networks and includes a remote-control interface known as TraCI(Traffic Control Interface), which allows dynamic modification of simulations, including real-time control of individual vehicles and pedestrians. For this study, SUMO Version 1.21.0 is used.

Fig. 2. Punjabi University Patiala (downloaded from “openstreetmap.org”)

To construct the simulation environment, a map of the selected region was obtained from OpenStreetMap.org and refined using JOSM (Java OpenStreetMap Editor) [41] and XMLStarlet [42]. The map was then processed using SUMO's NETCONVERT tool, ensuring that both road networks and pedestrian pathways were accurately represented. The resulting map image is shown in Figure 2. To enhance pedestrian movement simulation, parameters such as sidewalk generation and connection of adjacent pathways were configured within NetEdit, allowing for the creation of seamless, randomized pedestrian routes.

A custom Python script was developed to simulate a missing individual's movement. The script used an algorithm that generated random walking patterns, ensuring a realistic representation of how a person might navigate the environment. At the start of each simulation, the individual was randomly positioned on the network's pedestrian pathways. The movement was determined by selecting neighboring walkable paths, avoiding U-turns, and maintaining a maximum walking speed of 1.25 m/s. SUMO's non-interacting pedestrian model [43] was applied to regulate movement and interactions within the simulated environment.

For vehicle-related data, Google Maps satellite imagery was analyzed to identify on-street parking locations. These parking spots were then mapped as Points of Interest (POI) within the SUMO network. Each parking space was standardized to dimensions of 5m × 2.5m, following recommended guidelines [44],[45]. Based on satellite observations, parking orientations were defined as parallel or perpendicular to the curb. Each simulation involved placing the pedestrian on a random edge of the network and allowing them to walk until: An RFID-equipped moving vehicle detected their tag, triggering a location report or a time limit of 30 minutes expired without detection, marking a failure case.

The simulation scenario represented a realistic emergency response situation, where an administrative center activates the tracking system after receiving an alert from a caregiver or law enforcement. The 30-minute detection window was selected based on the need for rapid intervention, ensuring a missing person could be found before facing significant risks. To evaluate system performance, 20,000 simulations were conducted under varying participation rates, detection ranges, and sampling intervals. These variables' explanation is as follows:

A. Variables

In our experiment, we analyzed several parameters to create diverse test scenarios. These parameters included the proportion of parking spaces occupied by vehicles participating in the service, the detection range of the RFID reader, the equipment installed on these moving vehicles, and the sampling frequency of the RFID equipment. To ensure comprehensive results, we conducted 500 simulations for each scenario, totaling 80 distinct scenarios. These were derived from ten different participation rates, four varying detection ranges, and two separate sampling rates.

a) Participation Rates: We mapped various parking spaces of the university from Google Maps satellite imagery onto our SUMO network. Using this dataset, we evaluated how different participation levels affected our service. The proportion of occupied parking spaces was varied from 10% to 100% in increments of 10% to generate different test cases. At the start of each simulation, a specified percentage of parking spaces was selected accordingly and it remains constant throughout the simulation.

b) Detection Ranges: The read zones surrounding each RFID reader and antenna are influenced by multiple factors, including antenna orientation, angles, and tag-specific attributes. However, for the sake of simplicity, our experiment assumed uniform, circular, two-dimensional read ranges with radii of 4m, 8m, 12m, and 16m to create four distinct test scenarios. These circular detection zones were positioned around the locations representing the RFID reader and antenna mounted on each participating moving vehicle, specifically at designated POIs within the SUMO simulation map, which corresponded to occupied parking spaces. A detection event was logged when a person randomly entered or passed through at least one of these detection zones while a participating parked vehicle was actively scanning for RFID tags.

c) Sampling Rates: To evaluate detection performance under different conditions, we considered two distinct polling frequencies: (i) Continuous Scanning (Always On) and (ii) Intermittent Scanning at a rate of 0.02 Hz. If an individual was within range of an RFID-enabled moving vehicle that was actively polling at that moment, a successful detection was recorded. The simulation setup focused on estimating the likelihood that, during a given time step, an RFID-equipped parked vehicle would be scanned, assuming the individual was within detection range and the vehicle was part of the system.

B. Results

The data gathered for each test scenario includes: (i) the average detection time (in minutes) for locating the missing dementia patient, provided the detection occurred within a 30-minute interval of time from the start of the simulation; otherwise, the outcome was recorded as a failure. (ii) The population standard deviation (in minutes) from the average detection time, offering insight into the variability of detection times. (iii) The total number of failed detection attempts for each scenario.

In total, 80 distinct scenarios were tested, derived from the combination of ten different participation rates, four detection ranges, and two sampling rates. Consequently, a total of 40,000 simulations were executed throughout the experiment. The results of these simulations are presented below.

i) Average Detection Time: Figures 3-6 display the average durations, in minutes, required to locate the missing individual. These figures correspond to various participation rates and detection ranges tested under two polling frequencies: Always On and 0.02 Hz, respectively for moving and parked vehicles. The shortest average detection time was just 1.6 minutes for the proposed system whereas it was 2.08 mins for the parked vehicles-based detection system where the participation rate was 100%, the detection radius was set at 16 meters, and the readers operated continuously (see Fig. 3 and 4). In contrast, the longest average detection time was 3.264 mins in the case of the proposed system and 10.198 mins for the existing system when only 10% of vehicles were participating, the detection range was limited to 4 meters, and the readers polled at 0.02 Hz (see Fig. 5 and 6). So these graphs show that the proposed system improved the average detection time of the existing system [7] by 60% when the sampling rate is always ON and by 40% in the case of 0.02Hz sampling rate.

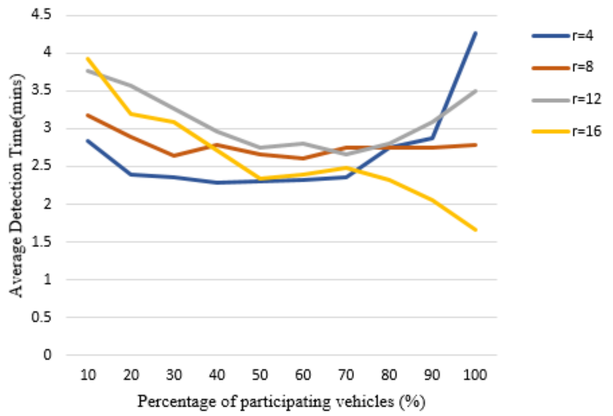

Fig. 3. Average Detection time (mins) for the proposed system at sampling rate always ON

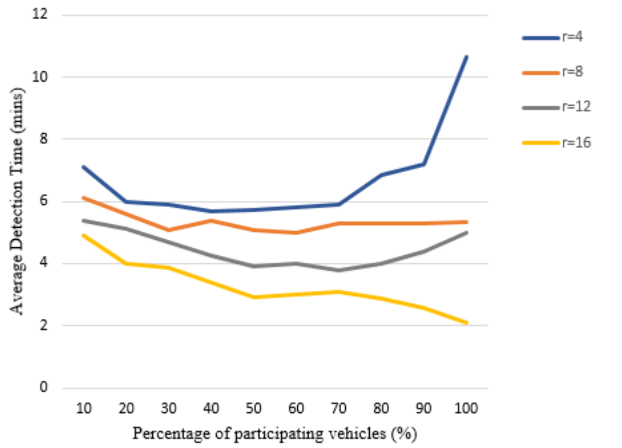

Fig. 4. Average Detection time (mins) for existing system at sampling rate always ON

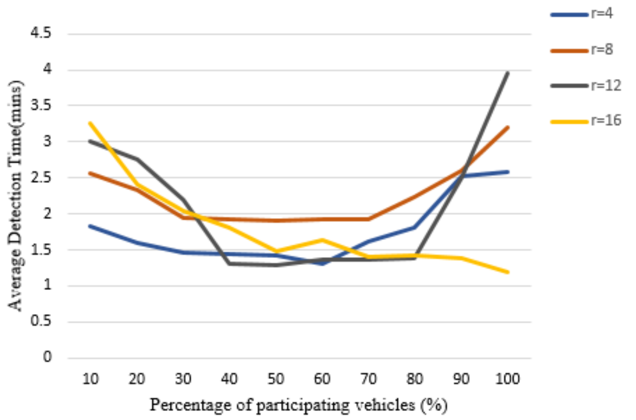

Fig. 5. Average Detection time (mins) for proposed system at sampling rate=0.02Hz

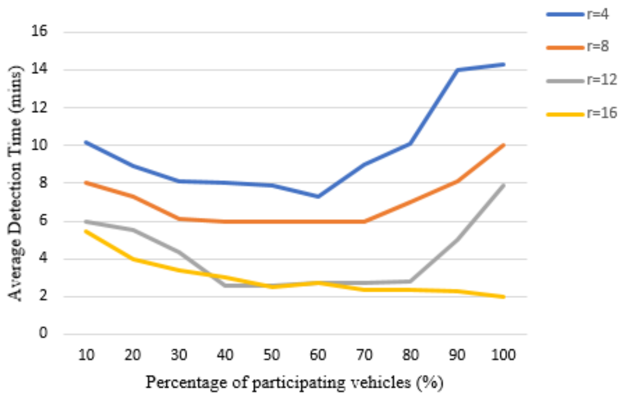

Fig. 6. Average Detection time (mins) for existed system at sampling rate=0.02Hz

ii) Population Standard Deviation: Figures 7-10 present the standard deviations, in minutes, from the average detection times discussed above for both systems. These figures correspond to the data shown in Figures 3-6 respectively.

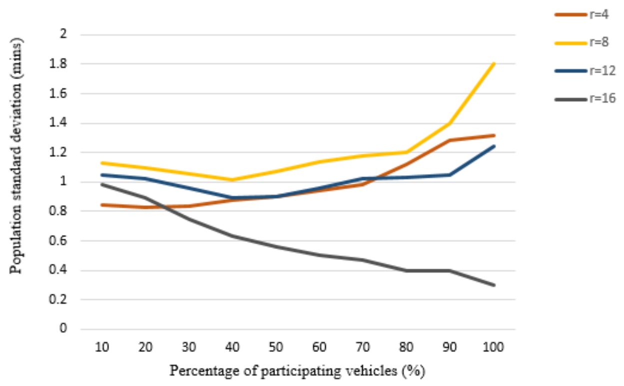

Fig. 7. Population standard deviation (mins) for proposed system at sampling rate always ON

iii) *Number of Failed Detection:* Figures 11-14 illustrate the absolute number of failures recorded per test scenario out of 500 simulations with identical parameters. The graphs exhibit exponential-like trends, with relatively stable failure counts starting from the 100% participation rate on the right side. Upon reaching a lower "threshold" participation rate, the failure counts increase sharply. Generally, the Always On polling rate outperformed the 0.02 Hz rate, as expected. Additionally, a detection range of 4 meters yielded the poorest performance. Specifically, combining a 4-meter detection range with a 10% participation rate and a 0.05 Hz polling rate resulted in nearly a 20% chance of failing to detect the individual within thirty minutes during any given simulation in case of proposed system (refer to the top grey line in Fig. 13). It is much improved than the existed system which has 50% chances in same scenario (refer to the grey line of fig. 14). Conversely, detection ranges of 12 and 16 meters, under sampling rate always ON, resulted in less than a 5% failure rate for proposed system and has less than 10% chances in existed system, indicating significantly better performance.

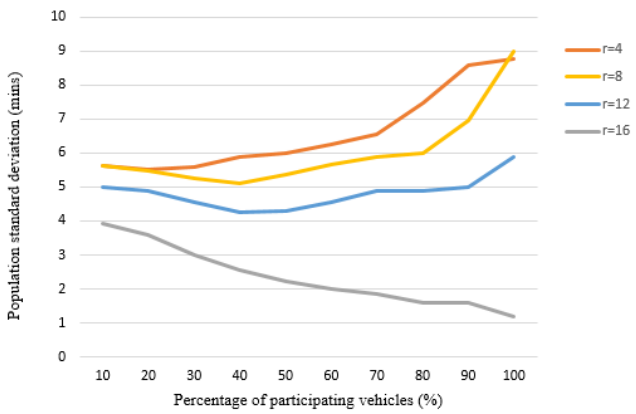

Fig. 8. Population standard deviation (mins) for existing system at sampling rate always ON

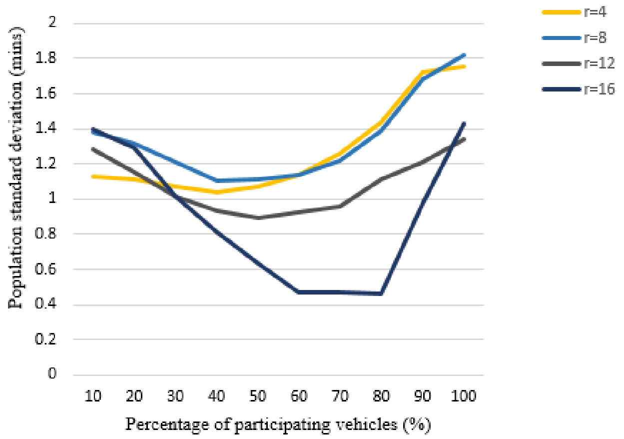

Fig. 9. Population standard deviation (mins) for proposed system at sampling rate=0.02Hz

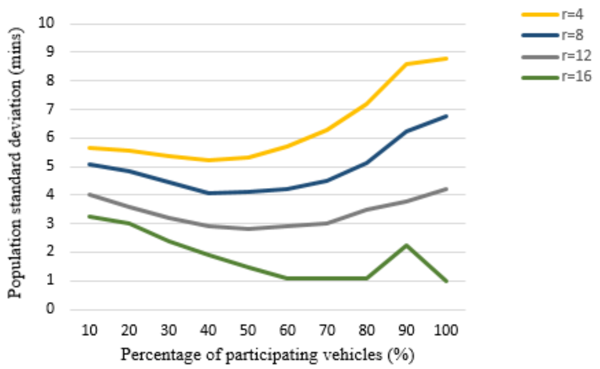

Fig. 10. Population standard deviation (mins) for existed system at sampling rate=0.02Hz

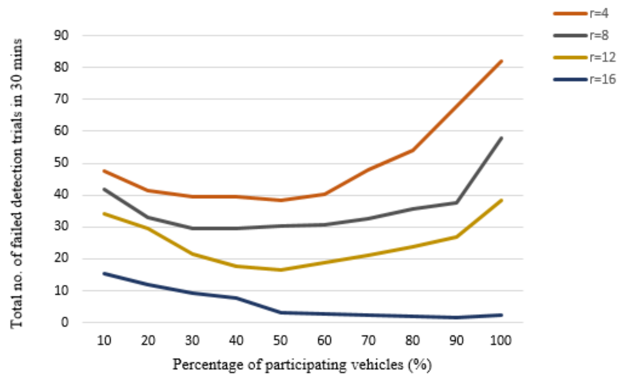

Fig. 11. Total number of failed detections in 30 mins for proposed system at sampling rate always ON

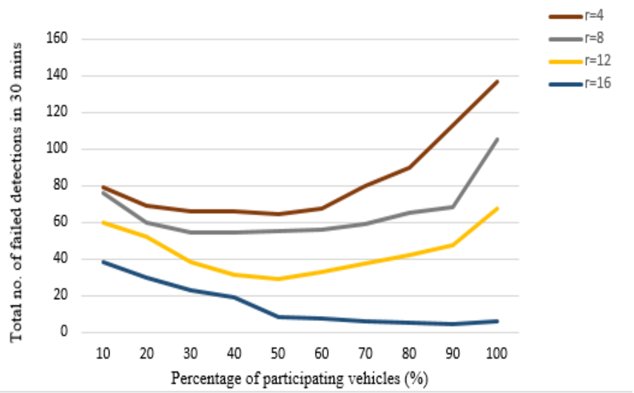

Fig. 12. Total number of fail detection in 30 mins for existed system at sampling rate always ON

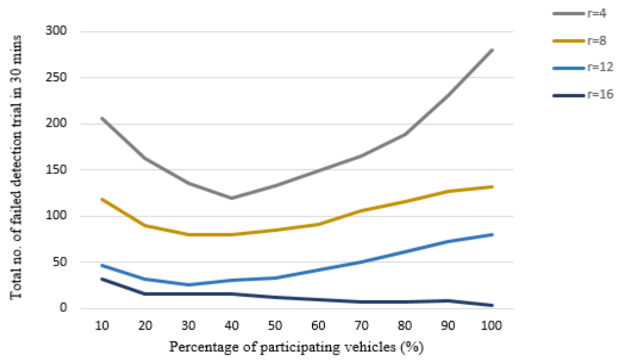

Fig. 13. Total number of failed detection in 30 mins for the proposed system at sampling rate=0.02Hz

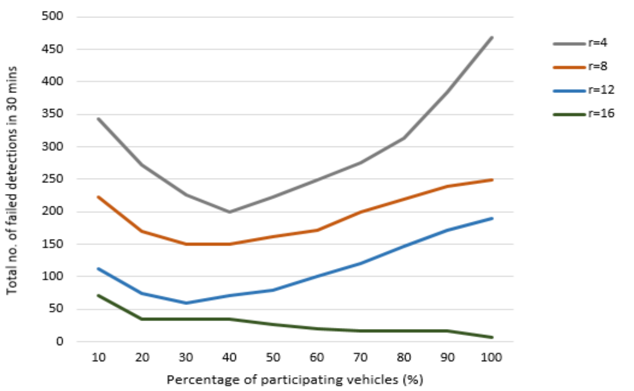

Fig. 14. Total number of failed detection in 30 mins for existing system at sampling rate=0.02Hz

5. Challenges and Future Scope

Implementing an RFID-based system to locate missing individuals presents several challenges like, technical challenges, privacy concerns, health considerations, encouraging participation and battery management, etc. The explanation of each challenge is as below:

i) *Technical Challenges:* Passive RFID tags require adequate power from incoming radio waves for detection. Detection success depends on:

• Attachment Material: Tags affixed to metal surfaces may reflect radio waves, while liquids can refract them, hindering detection [46].

• Tag Orientation: Improper alignment between the tag and the reader's antenna can impede detection.

ii) Proposed Solutions:

• Use silicone or rubber wristbands to house passive RFID tags, minimizing interference from metal surfaces.

• Equip individuals with wristbands on both wrists, each containing multiple tags, to enhance detection probability and reduce blind spots.

• Ensure RFID readers and antennas in vehicles are installed to prevent interference from the vehicle's metal components.

iii) Privacy Concerns: The deployment of numerous RFID readers and tags raises privacy issues, especially since unique tags are linked to individuals. Unauthorized tracking is possible without proper security. To mitigate this:

• Implement encryption and password protection to secure data access and transmission.

• Address potential threats such as tag spoofing, denial-of-service attacks, tag deactivation, and cloning.

iv) Health Considerations: To minimize health risks:

• Position RFID tags away from the head, particularly the eyes.

• Configure RFID readers so their read zones are below the neck.

• Use directional antennas to prevent UHF radio waves from penetrating the vehicle interior, protecting passengers and nearby individuals [47].

v) Encouraging Participation: To increase vehicle owner involvement:

• Offer incentives such as monetary compensation or exclusive services like premium parking spots [48].

vi) Battery Management: Passive RFID tags do not require power from the user. For vehicles:

• Ensure the onboard RFID system operates only when the car battery is sufficiently charged.

• For example, an 8-watt RFID reader running for 6 hours would consume about 10% of a standard 12V/40Ah car battery [49].

• Implement cooperative energy management among participating vehicles to extend operational periods without compromising battery health.

By addressing these challenges with the proposed solutions, the effectiveness and reliability of the RFID-based system for locating missing individuals can be enhanced.

We also recognize the importance of addressing ethical considerations related to patient privacy and data security [50]. Future work will involve developing robust protocols to ensure that patient information is protected in compliance with healthcare regulations. This includes implementing advanced encryption methods and access controls to safeguard sensitive data. Furthermore, expanding the system's interoperability with existing healthcare infrastructure is a priority. By ensuring compatibility with various electronic health record (EHR) systems [51] and medical devices, we can create a more seamless and comprehensive patient monitoring environment. This would facilitate better communication among healthcare providers and contribute to more coordinated patient care.

Finally, we intend to conduct extensive field studies to assess the system's performance in diverse healthcare settings. These studies will provide valuable feedback on the system's usability, reliability, and impact on patient outcomes, guiding further refinements and ensuring that the technology meets the practical needs of healthcare professionals and patients alike.

6. Conclusion

This study presents a novel RFID-based tracking system for dementia patients that leverages moving vehicles to address the limitations of traditional and parked vehicle-based tracking systems. By equipping public transport, taxis, and other moving vehicles with RFID readers, we significantly enhance detection coverage, reduce blind spots, and improve real-time tracking capabilities. Our comparative analysis demonstrates that the moving vehicle-based system outperforms the parked vehicle-based system, achieving faster detection times, lower failure rates, and greater reliability across various scenarios.

The proposed system offers a scalable and cost-effective solution for tracking wandering dementia patients, particularly in urban environments where vehicle density is high. However, the system also faces challenges, including technical limitations related to RFID tag detection, privacy concerns, and health considerations. To address these issues, we propose practical solutions such as optimizing tag placement, implementing encryption for data security, and ensuring safe exposure levels to radio waves.

Future work will focus on further refining the system's performance, addressing ethical and privacy concerns, and expanding its interoperability with existing healthcare infrastructure. Field studies in diverse environments will provide valuable insights into the system's real-world applicability and effectiveness. By continuing to innovate and address these challenges, we aim to develop a robust, reliable, and ethical solution that enhances the safety and quality of life for dementia patients and their caregivers.

7. References and Footnotes

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Author contributions

Manpreet Kaur[1]: Conceptualization, Methodology, Software and Simulations, Investigations; **Sukhwinder Singh Sran[2]:** Data curation, Writing-Original draft preparation; **Manoj Kumar[3]:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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