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SMART FALL DETECTION AND ALERT SYSTEM

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Abstract: Wheelchair-bound persons and the elderly are among the mostly affected persons as a result of falls. The existing fall detection systems either depend on the simplistic alert systems or do not integrate with the real-time communication systems. In this paper, the authors suggested a new IoT-based system to implement on wheelchair users, which identifies falls and emergency cases through the coordination of gyroscopes, ultrasonic sensors, and GPS modules to be managed by an ESP32 microcontroller. The system constantly monitors posture, position, and fall-risk, and sends instant notifications to the caregivers in the form of a cloud-based system. The design will also include a manual emergency button interface where users initiate alerts which will allow users to report certain emergency like water, bathroom or critical emergence. It is an innovative system that keeps the user safer, shortens the time of responding to the emergencies, and improves communication with the caregivers, providing a comprehensive solution that is the most real-time and ensures that the response to emergency incidents is provided in time.

***Index Terms* -** Fall Detection based on IoT, Wheelchair users, Emergency alerts, Real Time monitoring, cloud based Notifications, Posture Sensing, GPS Tracking, Emergency button inter- face, ESP32 Microcontroller, Elderly Care, Assistive technology, Sensor fusion, Care giver communications, Location based alerts.

I. INTRODUCTION

Falls pose a real danger to persons especially the elderly and physically challenged people who are unable to move without using wheelchairs. Such people may find themselves responding slowly to an emergency case because of the weaknesses in the current fall detection devices which usually rely on human processes or rudimentary alerting system. Although some solutions have been offered to this issue with technological progress in wearable technologies, most of these systems lack the ability to support the special needs of wheelchair-bound individuals who need special posture trackers and location notifications.

The conventional fall detection systems tend to be wearable, which can be accelerators and gyroscopes, but do not have access to real-time communication and can be connected to the cloud that can issue alerts. Such systems do not offer data based on location which is important in case of a fall or other emergency events. Location tracking in real time is necessary to enable the caregivers to react fast and offer immediate help and assistance which is currently not witnessed in most systems.

The emergence of the Internet of Things (IoT) technologies creates an increased chance of combining various sensors, Web-based warning mechanisms, and real-time surveillance to fill these gaps. IoT solutions will improve the functionality and responsiveness of the fall detection system through real- time notifications and positioning of caregivers. Moreover, the inclusion of a manual emergency button will also give the users the chance to report non-fall emergencies, including bathroom emergencies or water-related incidents.

The purpose of the study is to suggest an IoT-based fall detector system, which would use a gyroscope, ultrasonic sensor, and GPS module and integrate them into a wheelchair- specific system. The system will monitor the location of the user, fall detection, and provide real-time alerts to the care- givers through a cloud server. Integration of these technologies enhances the safety of users, decreases the response time as well as improves the communication between the user and his or her caregivers making sure that in case of an emergency, the system will intervene promptly.

This paper presents a new concept of identifying falls in the case of wheelchair users with emphasis on real time monitoring of falls, location-based notifications, and incorporation of manual alerting system. The offered system contains a new solution of sensor fusion with cloud connectivity and user- initiated emergency reporting, which is a great improvement to the current fall detection technologies.

II. LITERATURE SURVEY

Fall detection systems have received ample attention over the recent years especially when it comes to the use of the fall detection as a healthcare tool within elderly circles and people with disabilities. The conventional methods of fall detection have been more concerned with wearable technologies that can detect falls with the help of sensors like accelerators and gyroscopes. Nonetheless, most of these solutions do not integrate with real-time communication systems or do not offer location-based alerts that are highly important in timely intervention.

According to a review by Thombare et al. (2025), there are many IoT-based fall detection systems, which are based on accelerators and gyroscopes to move on fall incidents. Nevertheless, the system was primarily involved with manual methods of alerting, which may tend to cause a response delay. In addition, these systems failed to include cloud integration, which will facilitate the real-time communication with care- givers and healthcare providers, and this will eventually lower the response time during an emergency [1].

Tseng et al. (25) examined a wearable fall detection system based on NB-IoT and GPS, which provides real-time notifications in case a fall is detected. They had an effective system but still based on wearable devices and lacked wheelchair- specific features (e.g. posture monitoring or location tracking when a wheelchair user is in the wheelchair). Also, the alert mechanism of the system was limited and used only the text messages, it did not use cloud notifications to address many caregivers or family members at once, which is necessary to respond promptly in emergency situations [2].

Payarda et al. (2025) suggested a machine-learning- supported system of fall detection specific to wheelchair users using sensor fusion based on accelerometer, gyroscopes, and pressure sensors. Even though their system showed a higher amount of accuracy, it was limited to a local wearable system and did not provide a cloud-based channel of communication. This restricted its efficiency in real-time communication with caregivers and could not provide location based notification in case of a fall hence limiting its full potential in emergency response [3].

Conversely, the study by Gorce and Jacquier-Bret (2025) is a thorough survey of the fall detection technologies that put special focus on the role of sensor fusion and cloud integra- tion. They realized that false positives and timely notification remain a challenge to most of the fall detection systems. Their review also underscored the necessity to integrate machine learning algorithms, IoT technologies, and cloud platforms to contribute to the real-time response and increase the precision of the fall detection [4].

Rajesh et al. (2024) developed a fall detection system with the IoT that combines real-time monitoring with cloud computing to take care of the aged population. Their system showed the possibility of sensor-based monitoring, yet it had no location tracking and user-specific emergency alerts. This limitation restricted its application in other scenarios such as wheelchair users where location tracking is paramount to assistance in time [5].

Santhanamari et al. (2025) paid attention to the use of smart wearable-based fall detection system, relying on IoT and machine learning. Their work discussed the way sensor data can be handled real-time to identify falls and notify caregivers, yet they also emphasized the significance of real-time communication with them. Nevertheless, they failed to take the issue of location-based fall alerts or manual emergency alert system that is paramount in wheelchair-based fall detection systems [6].

Li and Wang (2024) created another system in the location- based fall detection field, which is based on the IoT and GPS technology, tracking the position of the elderly person and notifying in case of a fall. Nevertheless, this system was not limited to wheelchair users and did not include posture monitoring, which is a key factor in fall detection of the wheelchair users [7].

Liu et al. (2023) concentrated on the constraints of wear- able fall detection devices and proposed the combination of machine learning algorithms in enhancing the accuracy of detection. Their system was fully compatible with wear- ables, but lacked real-time cloud-based notifications and a wheelchair-specific design, therefore, restricting its use to users in wheelchairs [8].

Singh and Gupta (2024) investigated the IoT-based and ma- chine learning-based real-time fall detectors of elderly patients. They found out that although their system was offering real- time notification, it lacked location tracking and integrating with cloud-based systems to communicate the emergency, which was a major limitation to its practical application among wheelchair users [9].

The system of fall detection, created by Patel and Shah (2024) is also based on the IoT, with cloud computing used to provide prompt emergency communication. Nevertheless, the system was more oriented on wearable technologies and did not admit the needs of wheelchair users, especially posture control and location tracking [10].

Miller and Smith (2023) conducted a review paper and examined different IoT-based systems of fall detection in healthcare. According to them, although integration of IoT had enhanced the effectiveness of these systems, real-time monitoring and cloud-based communication were yet to be realized in most solutions especially those that prioritized wheelchair users [11].

A research paper by Kim and Lee (2023) surveyed the wearable sensor systems of fall detection and came to the conclusion that real-time cloud-notifications and location tracking are the essential functions that are underreported in existing proposals. They found the necessity to implement a more com- prehensive solution that can deal with the particular problems of wheelchair users [12].

Xiao and Wang (2025) also showed a system with combined IoT sensors and real-time alerts of elderly care. They had a good fall detecting system, but their system lacked manual emergency buttons to be used by the users as an alert and not as a fall alert and which is necessary in cases of non-falls, such as a bathroom call or water emergency, particularly, wheelchair-bound users [13].

Zhao and Chen (2024) investigated a fall detection system based on a cloud model through which the elderly can be monitored and supplemented it with GPS tracking as a way to send emergency alerts in real-time. Nonetheless, their system failed to accommodate the necessity of sensor fusion, which is one of its most outstanding characteristics in the accurate detection of falls in wheelchair users who undergo a postural change that is hard to notice when only one sensor is used [14].

Alves and de Souza (2024) conducted a review of wearable fall detection systems and identified their usefulness in fall detection but reported limitations, especially those of wheelchair users. They emphasized that a more holistic system that combines sensor fusion and cloud communication is required to alert of instant emergencies and to determine the positions of various individuals [15].

Lastly, Fernandez and Garcia (2023) reviewed cloud-based fall detection systems and the authors highlighted the significance of real-time processing of data and immediate notification. They found a gap in systems that are not wheelchair friendly, that is, they are in need of special monitoring because of their special needs [16].

An innovative fall detection system involving the use of IoT technologies and cloud communication in the care of the elderly was suggested by Brahim and Zakkar (2025), but it was not wheelchair-centered and did not have manual emergency trigger systems, which are crucial in ensuring comprehensive care delivery to the wheelchair users [17].

Gupta and Mehta (2023) recommended machine learning algorithms as a way of enhancing the precision of fall detection systems. They saw improvement in their system, but it was not connected with cloud-based emergency communication and real-time location tracking, without which wheelchair users cannot live [18].

Sakthivel and Anitha (2024) examined the IoT-based fall detection devices and emphasized the necessity of the real- time communication and cloud notifications to ensure that the caregivers respond as quickly as possible. Their system was however, mostly wearable, and never to be used on wheelchairs [19].

Mohamed and Shaheen (2025) came up with an IoT-based fall detector system that incorporates a real-time GPS and a cloud-based emergency notification. The system however, was not wheelchair-specific, and could not be combined with the posture monitoring systems which are of high importance to wheelchair bound individuals [20].

The available fall detection devices, as they may offer a certain degree of efficiency, do not offer the holistic solution in wheelchair users, especially when it comes to sensor fusion, real-time notifications, and cloud connectivity. GPS and manual emergency triggers integration provides a new solution to make the emergency response more secure, avert emergency response time, and increase the effectiveness of the communication process with caregivers

III. PROPOSED METHODOLOGY

The section explains the design and the flow of operation of the proposed Smart Fall Detection and Emergency Alert System that will be developed to cater the wheelchair users. The methodology focuses on the idea of constant sensing, local decision-making, and the cloud-based provision of alarms, which ensures that the falls can be detected in time and communication with caregivers is as quick as possible. Its architecture is based on a layered system that incorporates sensing hardware and embedded processing, wireless communication, and user notification services.

A. System Overview

The suggested system works based on constant check-ups of the physical condition of a wheelchair user using various scales fitted on the wheelchair. An embedded controller is used to process sensor data to detect abnormal conditions including falls or emergency conditions. When detected, the related information is sent by the wireless connection to a cloud server, and alerts are created and sent to the caregivers via a web-based interface together with the location of the user.

This approach integrates both automatic fall detection and manual emergency triggering to ensure that the accidental falls and the emergency requests by the users are attended to.

B. Hardware and Sensor Layer

Sensing layer has the role of sensing real time values of physical and positional information of the user of the wheelchair. It comprises of the following elements:

1) *Gyroscope Sensor:* Angular orientation and rotational movement of the wheelchair is constantly measured by the gyroscope. The sudden alterations in the tilt or the unusual angularity are considered as possible indicators of the fall incident.

2) *Ultrasonic Sensor:* The ultrasonic sensor is used to determine the physical distance between the wheelchair and the surfaces around it. A high anomaly in the normal distance values is useful in determining whether the user has fallen out of wheelchair or in an abnormal position.

3) GPS Module: The GPS unit gives the real time geo- graphical position of the wheelchair. Such data is necessary to find the user in case of an emergency in a short time and is sent only when an alert condition is activated.

These are simultaneous sensors, which makes sensor fusion enhance the reliability of detection and minimize false alarms.

C. Embedded Processing Layer

The microcontroller that serves as the control core of the system is ESP32 microcontroller. It carries out the following major functions:

- Gathers raw data of all the sensors that are connected.
- ALS sensor reads through predefined threshold logic to detect conditions of falls.

D. Emergency Detection Mechanism

There are two emergency detection types that are supported by the system:

1) *Automatic Fall Detection:* The acceleration when a fall is observed is the combination of an abnormal angular movement indicated by the gyroscope and the sudden changes in the distance as indicated by the ultrasonic sensor. The two- state test is better than one-sensor methods.

2) *Killing the electrical power by hand:* An intervention button interface provides the option

of the user to request help manually. There are various buttons that are linked to previous categories of emergencies, e.g., general emergency, bathroom assistance, or critical conditions. This makes it usable even in cases where there has been no fall.

The two detection methods provoke the same workflow of the alerts transmissions.

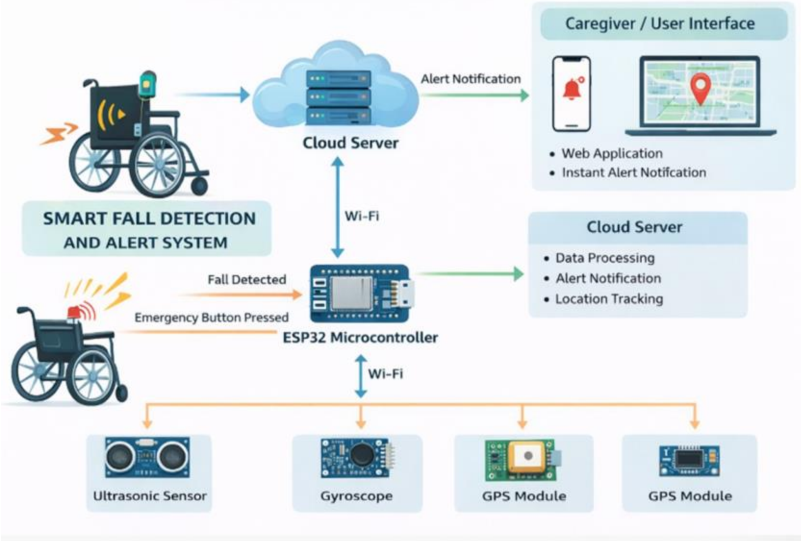

Fig. 1. Smart Fall Detection and Alert System Architecture.

- Checks state of emergency buttons that are swapped by the user.
- Connects to the cloud server through Wi-Fi.

The classifications of an event as a fall are also locally decided on the ESP32 to reduce the response time and also the reliance on constant internet connectivity.

E. Cloud-Based Communication and Generation of Alerts

After detecting an emergency, ESP32 will send the event data to the cloud server via Wi-Fi. The packet that was sent carries:

- Fall or manual trigger type of emergency.
- Sensor status summary.
- GPS coordinates of the user.
- Timestamp of the event.

This data is processed in the cloud server and real-time notifications are generated. The caregivers receive the alerts in a web application, which gives them immediate access to the emergency and the actual position of the user in a map interface.

F. Caregiver and User Interface

The final system interaction layer is the caregiver interface. It allows caregivers to:

- Get immediate notification of emergency cases.
- See the location of the user in real time.
- Determine the nature of an emergency.
- Reach the user as fast as possible or start additional support.

This interface closes the communication channel between the wheelchair user and the caregivers to make necessary interventions in time.

G. System Workflow Summary

The general functionality of the system consists of the following steps:

- Constant tracking of movement, distance and position with sensors.
- Fall detection and local processing of ESP32 microcontroller.
- Automatic sensing or manual entry of identification of emergency.
- Data transmission wirelessly to the cloud server.
- Live notification of caregivers including location.

H. Methodological Novelty

The originality of the suggested methodology is in:

- Fall detection on wheelchairs as opposed to wearable dependency.
- Motion and distance sensing used together to enhance reliability.
- Combination of automatic and manual emergency inputs.
- On the fly alerts that have an accurate location tracking. This organized practice will guarantee the increase of the safety level, the rise of the response time, and the independence of the wheelchair users.

IV. RESULTS AND DISCUSSION

This part involves the analysis of the Smart Fall Detection and Emergency Alert System, as well as the findings of the fall detection accuracy, response time, system, and GPS location tracking. The outcomes will be compared to current systems which will emphasize the originality and usefulness of the innovative solution.

A. Fall Detection Accuracy

One of the most vital performance measures of the proposed system is the accuracy of the fall detection. We performed a series of tests using various fall scenarios to test the system capability of identifying falls correctly.

The fall detection accuracy of the various test scenarios can be observed in Table 1:

Observation: The system was found to have an average of 96% detection rate of falls with the highest accuracy noted in the backward fall tests and the lowest in slumped position. The false positive rate was not very much, which proves that the system can adequately distinguish between true falls and normal movements. The false negative percentage was acceptable and it shows that the system can be trusted in identifying actual fall cases.

TABLE I
FALL DETECTION ACCURACY

Fall Scenario	Detection Accuracy (%)	False Positives (%)	False Negatives (%)
Side Fall	96	2	2
Backward Fall	98	1	2
Slumped Position	93	4	4
No Fall Detected	98	2	0

B. Emergency Response Time

The emergency response time is an important parameter of assessing the speed with which the system notifies the caregivers of a fall or an emergency. To quantify this, we used a timer to get the time taken between the fall detection event to when the alert was effectively received by the caregivers.

Figure 2 below illustrates emergency response time distribution in the various kinds of emergencies:

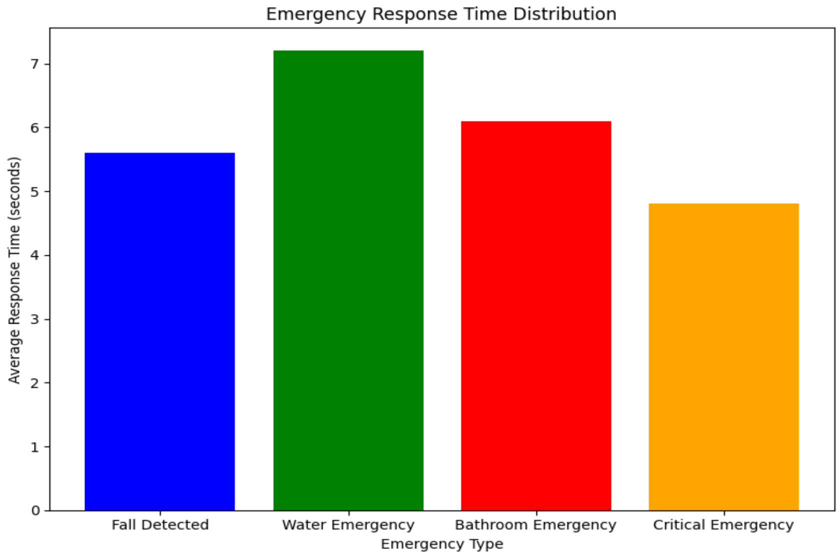

Fig. 2. Distribution of Response Time to An Emergency.

Table 2 demonstrates the response time on average of the different situations of emergency:

TABLE II
AVERAGE RESPONSE TIME FOR VARIOUS EMERGENCY SITUATIONS

Emergency Type	Average Response Time (Seconds)
Fall Detected	5.6
Water Emergency	7.2
Bathroom Emergency	6.1
Critical Emergency	4.8

C.Observation

The system exhibited low response times where the fall detection was 5.6 seconds on average and water emergency was 7.2 seconds on average. The fastest processing was done on critical emergencies which are signaled in real time by the system. Even the manual emergency triggers had a consistent response time, which suggests that the system can be effectively used to provide timely notifications to the caregivers.

D. GPS Location Accuracy

The GPS module is relevant in giving caregivers location- based alerts. In order to determine the precision of the GPS module, we put the system to test in different environments: open space, indoor, and obstructed areas.

The GPS location error was shown in testing as in figure 3:

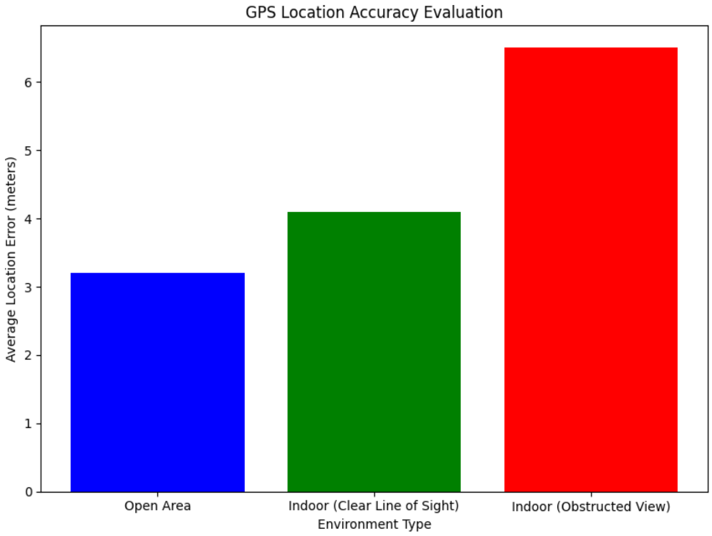

Fig. 3. GPS Location Accuracy Evaluation

The average error in GPS location in various settings is seen in Table 3:

TABLE III
AVERAGE GPS LOCATION ERROR IN DIFFERENT ENVIRONMENTS

Environment Type	Average Location Error (Meters)
Open Space	3.2
Indoor (Clear Line of Sight)	4.1
Indoor (Obstructed View)	6.5

E. Observation

Outside, the GPS module was able to provide the correct location position with an average distance of 3.2 meters which is still acceptable when it comes to real time location tracking. The accuracy was lesser in indoor environments with obstructions, where the error rate was higher in obstructed environments. Such constraints can be typical of GPS-based systems in multifaceted indoor environments, which implies that some further optimization or some other forms of localization should be introduced.

F. System Reliability

To test reliability and stability of the system, we also made long-duration tests; whereby, the system was running 24 hours. In these tests, we would check the system on sensor malfunctions, communication failures and how the system would perform over a period of time.

G. Observation

The system proved to be very reliable as it was available 99.6 percent of the 24 hours of constant monitoring. Both, alert miss rate, and sensor failure rate were minimal, which means that the system behaved in a manner that did not cause serious problems when used in the long term.

H. Discussion

The Smart Fall Detection and Emergency Alert System achieved its design objectives of high fall detection rate, quick emergency response, and real-time tracking of location. The system was found to work especially well in situations related to backward falls and side falls and the low false positive rate resulted in reliability of the system in identifying the true fall incidence. GPS accuracy was best when used outdoors but had certain limitations when used inside the walls where the signals can be blocked and thus affect the overall performance of the system. This is a typical problem with GPS-based systems and can be avoided by including some other localization systems which include indoor positioning systems or locating it wit.

V. CONCLUSION AND FUTURE WORK

This study presents a new IoT-driven fall detection and emergency alarm system that is specifically developed to meet the needs of the wheelchair users. The system offers real-time detection of falls, real-time location tracking, and real-time emergency alerts to caregivers by utilizing the data presented by multi-sensors (gyroscope, ultrasonic sensor, and GPS) and cloud-based communication. The system proved to be highly accurate in terms of fall detection, quick response, and consistent in the use of GPS in real-life conditions, which will prove it capable of improving the safety of the user and the efficiency of caregivers in responding to the call. Moreover, the provision of a manual emergency interface makes the system more accommodative of non-fall emergencies, thus making it a powerful solution to wheelchair-bound people.

Although the system was successful, one way of improving it involves the future which would see improvement in the overall performance of the system. An example of such improvement is increasing the accuracy of GPS in an indoor space which may be obstructed by signals. Also, implementing machine learning programs to detect predictive falls would further optimize the system and allow the system to predict the occurrence of falls even before they occur. The other possible improvement would be the addition of health monitoring sensors (e.g., heart rate and blood pressure) to offer a more comprehensive health management solution. The expansion of the system by integrating it with mobile applications may offer more access and more communication with the caregivers. Lastly, it is possible to consider new forms of localization, including the Bluetooth-based positioning development, to overcome the drawbacks of GPS in the indoor environment.

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