International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 14, Issue 4 [April. 2025] PP: 09-15

A Wearable Fall Detection System Using ESP32 for Elderly

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ABSTRACT: *Falls have become one of the critical health factors in older people. It generates huge physical trauma, and hospitalisation time, and deteriorates their quality of life. Such challenges are presented by designing a novel wearable fall detection system aimed at improving safety for elderly subjects. The presented device represents two programmable ESP32 microcontrollers, one MPU6050 sensor, and a NEO-6M GPS module. This wearable can detect falls by collecting runtime motion and orientation data from the MPU6050 sensor. Immediately upon detecting any fall, it uses the WhatsApp API to send notifications with information such as the user's location to all caregivers. Location tracking using the NEO-6M GPS module, along with an on-site buzzer and LEDs, provides audible and visual alarm notifications. Compact, light, and relatively cheap, it should be an easy-to-handle device for every day This paper bridges significant gaps in care for the elderly with an easily implementable low-cost, scalable solution for reducing a variety of risks emanating from falling.*

Date of Submission: 02-04-2025 Date of acceptance: 12-04-2025

I. INTRODUCTION

The elderly population is particularly more prone to falls because their bodies may have declined in balance and other health problems. Injury from a fall usually involves some forms of physical trauma such as fractures and head injury, and psychological impacts include fear of falling again and social withdrawal [1]. The WHO reports that falls are the second leading cause of unintentional injury deaths worldwide. With the world population still ageing, there is an increasing need to develop effective and low-cost fall detection systems. A fall-detecting system monitors continuously detects the falls and informs instantly for ultimate safety and independence. The injuries caused by falls also incur heavy healthcare costs; its early detection and prompt intervention reduce the intensity of the injury and thereby decrease the cost. They reassure elderly people, hence encouraging active life and social involvement, consequently, improving the quality of life of this group [2-3].

Most systems already existing are very costly and, in most cases, unavailable, particularly in low-income setups [4]. It can be widely distributed and render fall detection technology available to a broader section of the population. The digital divide could limit some elderly people from using modern health monitoring systems. Towards this end, the system has friendly interfaces with clear messages of alerts based on its ability on educational programs, which improve digitization literacy and empowerment. The rapid alert of the emergency contact provides timely medical response [5-7]. This helps to better the community health outcomes. Most of the existing fall detection technologies, involving wearable devices, camera-based systems, and ambient sensors, suffer from some drawbacks concerning affordability, accuracy, or accessibility [8-9]. Many systems are based on expensive equipment that needs continuous monitoring, which makes them unsuitable for common use [10-11]. This work explores the overcoming of the disadvantages by implementing a non-intrusive, low-cost wearable device based on IoT technologies. This system is expected to detect falls reliably, enable immediate notifications in real time, and improve the safety and independence of older adults.

The primary objective of this research is to design and implement a fall detection system that can reliably and efficiently identify falls among the elderly. The secondary objective is to develop a system that can automatically alert healthcare providers or designated emergency contacts upon the detection of a fall, enabling prompt response and assistance. The project leverages the mobile application to design a wearable fall detection system that detects falls and sends notifications and location information to caregivers or emergency services. The system integrates the MPU6050 sensor, Neo-6M GPS module, and two types of ESP32 microcontrollers; ESP32-C3 and ESP32 to create a compact and effective fall detection system [9-11].

II. SYSTEM DESIGN

The system utilizes two types of ESP32 microcontrollers: ESP32-C3 which acts as a wearable device collecting data from an MPU6050 sensor, while ESP32 receives the data and sends notifications through the WhatsApp application. The NEO-6M GPS module provides real-time location tracking. The wearable is equipped with a buzzer and push buttons for user interaction. Utilising ESP-Now protocols to make sure the system is more compact and lightweight by making it 2 separate parts to become a wearable device and a communication Hub. The system design prioritizes compactness and energy efficiency, ensuring ease of use and reliability. Fig. 1 shows the block diagram of the system design. The data from MPU6050 and Neo-6m GPS module are continuously read by ESP32-C3. After it exceeds the falling threshold using data from MPU6050, GPS data from Neo-6m will be sent to other ESP32(2) through ESP-NOW. When the data is received at ESP32(2) it will display the ID and location through Liquid Crystal Display (LCD) and will be on the buzzer. Then, ESP32(2) will send the notification via the WhatsApp application Bot to notify the caregiver and the person such as their child or relatives.

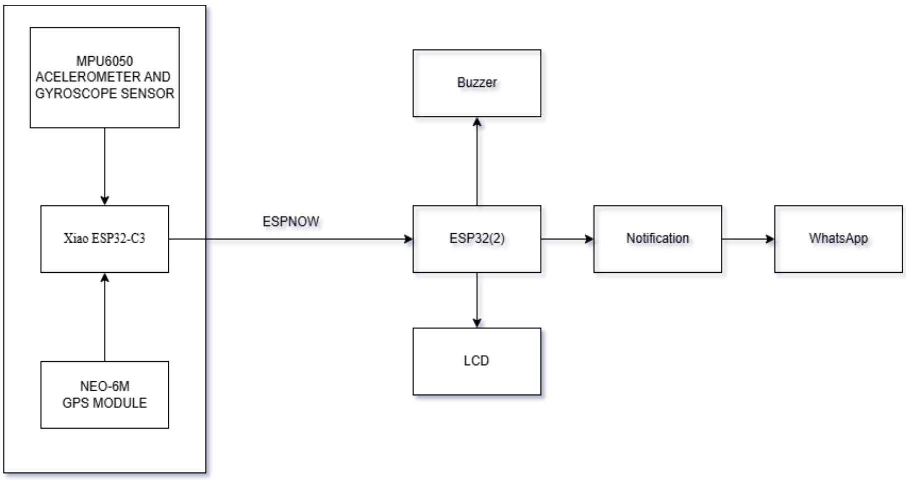

Fig. 1 The block diagram of the fall detection system

III. HARDWARE IMPLEMENTATION

The hardware implementation of the wearable fall detection system will involve choosing and incorporating the components with care to find an optimal balance between functionality, compactness, and energy efficiency. Therefore, the project requires 2 pieces of hardware set as a receiver and a sender. The sender should be as compact and lightweight as possible for the comfort of the elderly, While the receiver should act as a terminal to receive data from the sender using ESPNOW protocols. The Sender part includes ESP32_C3, MPU6050 and NEO-6M GPS and push buttons.

ESP32_C3: XIAO ESP32C3 by SeeedStudio is an ESP32 microcontroller which is compact, and powerful based on the Espressif ESP32-C3 chip. This board includes an external antenna to increase the signal strength for wireless communication such as Wi-Fi, Bluetooth, Radio signal and more. The Xiao ESP32-C3 is small in size and can be used as a limited-space microcontroller with many features. The reasons for choosing this microcontroller are this board compatible with Arduino IDE for programming, small for limited space for wearable devices, has low power consumption and has numerous GPIOs which are 11 digital Inputs/outputs that can be used as PWM pins, 3 analogue input/output that can be used as ADC pins. For this project, it acts as a sender to send the data from the MPU6050 sensor and GPS module Neo-6M.

MPU6050 is a 6-axis motion sensor that combines a 3-axis accelerometer and a 3-axis gyroscope. It is used to detect changes in motion, acceleration, and rotation. The accelerometers measure the static acceleration due to gravity and dynamic acceleration caused by motion such as daily activities, shock, and vibration. Theoretically, in a static object, the acceleration over the Z-plane is equal to the gravitational force which is 9.8 ms-2 while the X-plane and Y-plane should be zero. Furthermore, a gyroscope is used to measure rotational velocity or the rate of change of the angular position over time, along the X, Y, and Z-axis which are indicated as roll as the X-axis, pitch as the Y-axis and yaw as the Z-axis. By combining the information from both accelerometer and gyroscope, the information about sensor orientation will be more accurate. The accelerometer provides static acceleration data, while the gyroscope provides dynamic rotation data. Table 1 shows the connection of the MPU6050 pins to ESP32-C3.

Table 1: The connection of mpu6050 to ESP32-c3

Pins	ESP32-C3
VCC	3V3
GND	GND
SCL	GPIO7
SDA	GPIO6

The Neo-6M GPS module is a DPS receiver which is compatible with most microcontroller boards. It provides location data, which can be used to track the patient's location in case of an emergency or fall, enabling quick assistance. It comes with a GPS ceramic antenna, but it can be changed into any compatible antenna that is suitable for the project. For this project, a GPS ceramic antenna is used. The table below shows the connection of the MPU6050 pins to ESP32-C3.

Table 2: The connection of Neo-6m GPS module to ESP32-c3

Pins	ESP32-C3
VCC	3V3
RX	TX
TX	RX
GND	GND

Push buttons used in this system will allow the manual overrides and resets**.** The push button was set as a pull-down pushbutton which means that it by default is in a low state. When the push button is pressed, then the pin will be in a high state. Connecting with the resistor 10kOhm.

Based on the hardware for the sender, the ESP32-C3 will collect the data on acceleration and angle changes from MPU6050, when, it meets the threshold to the system, The sender will send the data from MPU6050 and GPS module Neo-6m through ESPNOW protocols to ESP32. The schematic circuit for the sender part is shown in Fig. 2.

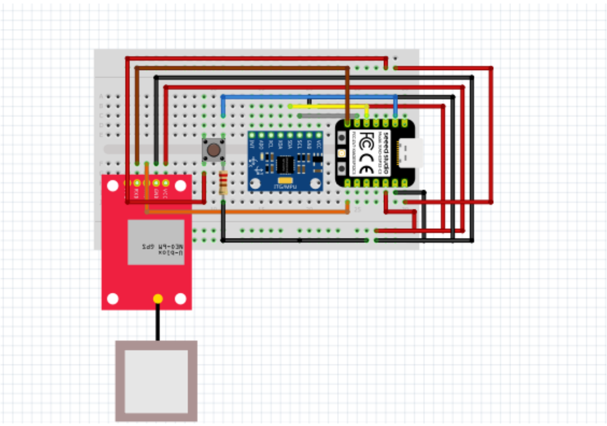

Fig. 2 The connection of the sender part

While the sender part include ESP32, buzzer and the LCD. ESP32 by the Espressif system functions as the communication hub. The ESP32's built-in Wi-Fi capabilities and GPIO pins make it ideal for IoT applications. A buzzer is used to generate audible alerts in the event of a fall that can alert the caregiver. The buzzer was connected to Pin D5 of ESP32. And the I2C LCD (Liquid Crystal Display) is used for this system and its connection pin is shown in Table 2.

Table 3: The connection between I2C LCD with ESP32

I2C LCD	ESP32
GND	GND
VCC	VIN
SDA	GPIO 21
SCL	GPIO 22

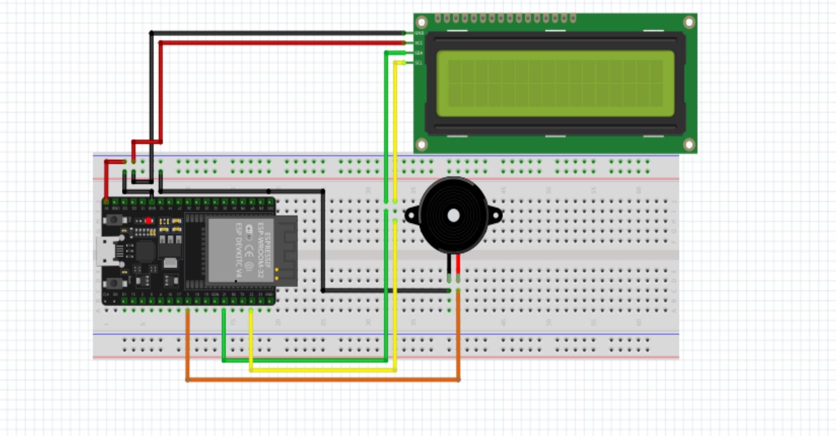

Fig. 3 The connection between the buzzer, LCD to ESP32 as the receiver

IV. SOFTWARE INTEGRATION

The system's software is developed using the Arduino IDE. Key functionalities include fall detection algorithm, ESP-NOW Protocol and WhatsApp notification API:

The fall detection algorithm processes raw data from the MPU6050 sensor that is connected to ESP32-C3, calculating the acceleration and angle changes of motion using accelerometer and gyroscope readings. The formula used for the accelerometer Sudden spikes in acceleration, then sudden static in acceleration and angle changes for a minute are interpreted as falls. The system then triggers alerts, sending notifications through the ESP-NOW communication protocol to ESP32. The acceleration is determined by calculating using accelerometer data while the angle changes using gyroscope data. The formulas used for calculating acceleration and angle changes are:

$$\text{Acceleration (A)} = \sqrt{aX^2 + aY^2 + aZ^2}$$

$$\text{Angle Changes } = \sqrt{gX^2 + gY^2 + gZ^2}$$

For this fall test algorithm, there were 2 triggers which were Trigger 1 was set as normal activities or Activity Daily Life (ADL) and Trigger 2 set as High Acceleration which had been detected by MPU6050.

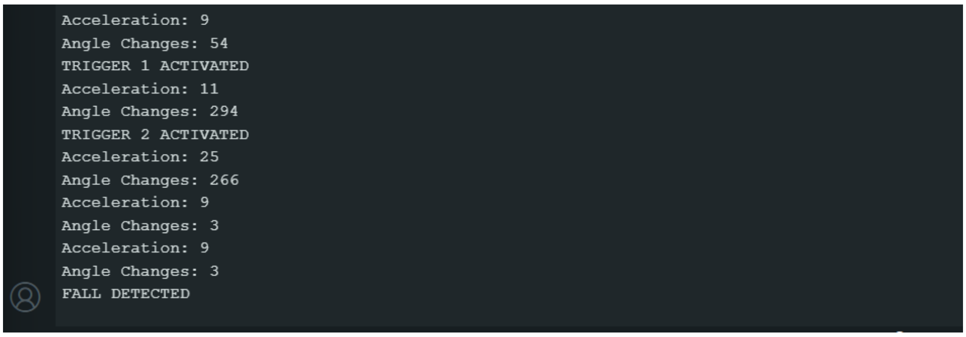

Fig. 4 The system testing shows that triggers 1 & 3 been triggered

Espressif Systems developed ESP-NOW, a low-power wireless communication protocol designed especially for ESP32 and ESP8266 devices. This protocol allows for efficient, low-latency communication between multiple devices without requiring a regular Wi-Fi network. It uses the 2.4 GHz frequency range and runs on a peer-to-peer architecture. Additionally, broadcast and unicast communications are supported by ESP-NOW. Furthermore, it can be applied to device-to-device communication, sensor networks, and remote monitoring systems. For situations requiring real-time data transfer with minimal setup, ESP-NOW is excellent.

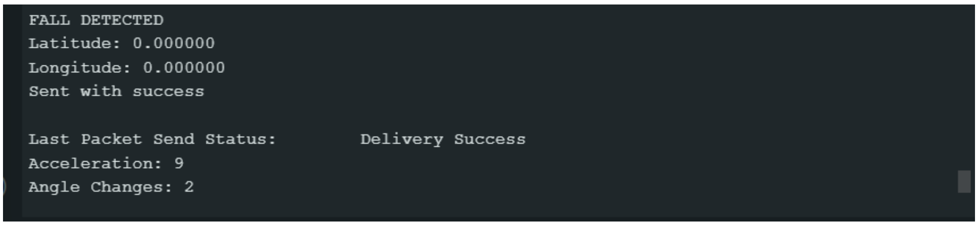

Fig. 5 The sender that sends the data through ESP NOW

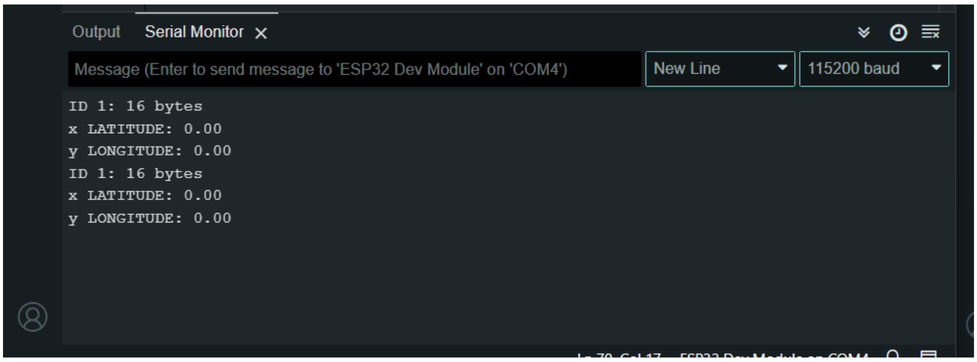

Fig. 6 The receiver received the data sent by the receiver via ESP NOW

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To enable remote communication, the device employs the WhatsApp Notification API, which delivers real-time messages to caregivers. These messages include the user's location, as determined by the GPS module. This feature ensures that caregivers receive immediate and actionable information about the fall event, facilitating prompt response. CallMeBot provides an unofficial way to send WhatsApp messages by using API. It relies on authenticating phone numbers for sending messages. One of the advantages of using this bot is that it allows you to interact with ESP32 remotely, without having to physically access it. This can be useful if the user wants to control the ESP32 from a different location or wants to monitor it remotely. The steps involved to create the CallMeBot API such as Save CallMeBot numbers into phone contacts, Send a Message to the CallMeBot number with the text "I allow callmebot to send me messages.", Waiting for a reply. The CallMeBot will respond with personal API keys which provided to send messages and integrate code into the system.

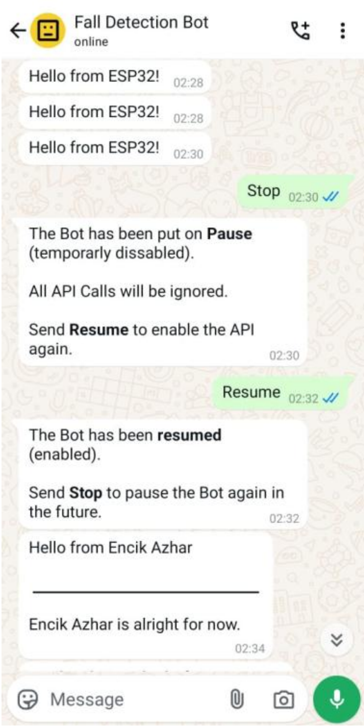

Fig. 7 Testing the WhatsApp Bot using CallMeBot API

V. RESULTS AND DISCUSSION

During controlled testing, the fall detection system demonstrated an overall accuracy of 95%, with a false positive rate of 4%. The average latency from fall detection to caregiver notification was approximately 30 seconds.

Table 4: The testing result of system based on three different activity daily life (ADL)

Test Scenario	Number of Tests	Fall Detected / True Positive (TP)	False Positive (FP)	Missed Falls / True Negative (TN)	Accuracy (%)	Latency (Seconds)
Forward Falls	20	18	0	2	90	10
Backward Falls	20	18	1	1	94	9
Sideward Falls	20	17	2	1	94	9
Activity Daily Life	30	8	2	N/A	N/A	N/A
Overall	60	32	5	4	93	9

Tests conducted with controlled falls (backwards, forward, and sideways) showed consistent detection performance. However, activities of daily living such as rapid sitting or lying down occasionally triggered false positives, highlighting the need for further algorithm refinement. For analysis effectiveness of the fall detection system based on the parameters using the accuracy standard formula where the system's ability to identify the actual falls while recognizing the false falls.

$$Accuracy = \frac{TP}{TP + TN} \times 100$$

Where TP is the true positive indicated number of falls detected, False positive (FP) indicates false falling events detected. True negative (TN) indicates the falling event is not detected by the system and False negative (FN) indicates activities of daily life (ADL) not detect as a fall event.

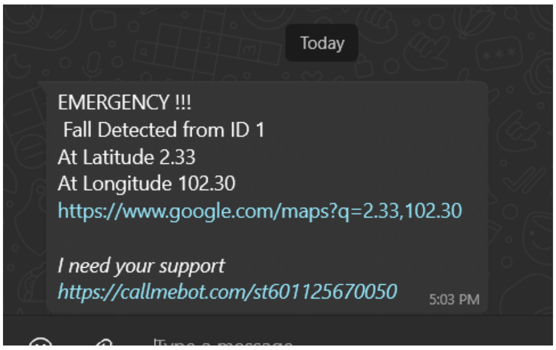

Fig. 8 The notification from the WhatApps application

The Notification WhatsApp was sent from ESP32(2) that contains the ID number of the elderly, that sentence of fall detected from the person. The location of the elderly was latitude and longitude. Then, the Google map location is based on the latitude and latitude given.

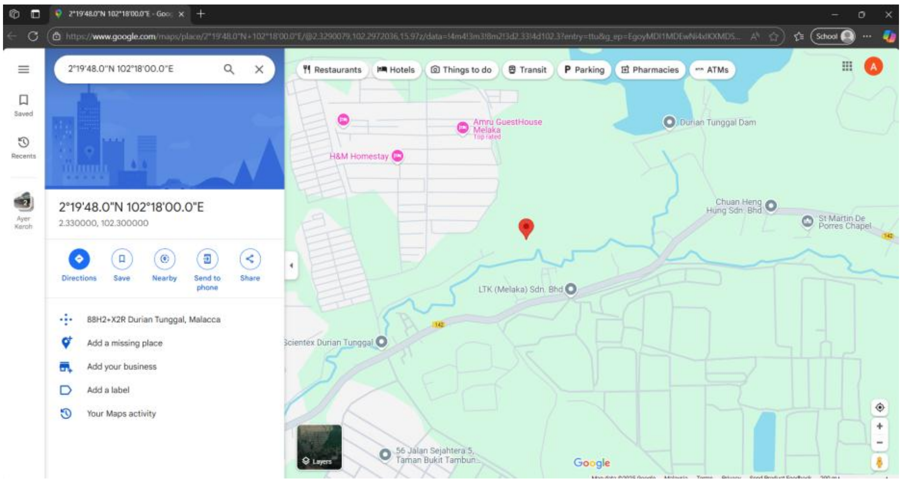

Fig. 9 The location in GoogleMaps from the link given in WhatApps message

The MPU6050 sensor performed reliably in detecting sudden motion changes, while the NEO-6M GPS module provided accurate location data within a 5-meter radius. The integration of the WhatsApp API ensured timely and accessible notifications to caregivers, offering a user-friendly communication platform. Challenges included simulating slow or gradual falls and managing power consumption during prolonged use. Future work will address these issues by incorporating additional sensors and optimizing the system's power efficiency. These results demonstrate the system's potential to significantly enhance elderly safety and emergency response times.

VI. CONCLUSION AND FUTURE WORK

This study successfully developed a cost-effective and reliable wearable fall detection system tailored to the needs of elderly users. By combining advanced sensor technologies, real-time communication, and a compact design, the system addresses critical gaps in elderly care. The device’s ability to detect falls with high accuracy and deliver immediate notifications demonstrates its potential to enhance safety and independence for elderly individuals. Future enhancements will focus on improving sensor accuracy by integrating additional components, such as barometers and magnetometers, to differentiate between falls and non-fall activities more effectively. Power optimization strategies, including advanced sleep modes, will be explored to extend battery life. Furthermore, the development of a dedicated caregiver application will provide real-time monitoring and enhanced user interaction. Additional functionality, such as health monitoring features for heart rate, oxygen saturation, and blood pressure, will expand the system’s utility. By addressing these areas, the system can evolve into a comprehensive solution for elderly safety and health monitoring, further strengthening its impact and commercial viability.

ACKNOWLEDGMENT

The authors would like to thank Fakulti Teknologi Kejuruteraan Elektronik Dan Komputer, Universiti Teknikal Malaysia Melaka for supporting this project.

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