AN INTELLIGENT WEARABLE AND MOBILE SYSTEM FOR THE AUTOMATED FALLING DETECTION AND PROTECTION USING MACHINE LEARNING AND INTERNET-OF-THINGS

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ABSTRACT

In today's society, elderly adults living alone face various challenges. From this we can feel the indifference of modern society and the danger of falling for elderly people living alone. By recounting my grandfather's personal experience of a fall, the urgent need for assistance among elderly adults and the potential dangers of isolation are highlighted. The core question is: How can technology be used to improve the safety and overall quality of life of elderly adults living alone [1]? To solve this serious problem, we developed a fall detection device. When elderly adults wear fall detection devices, it can address these challenges by providing a mechanism to send instant alerts to family members through a connected app in the event of a fall or emergency. The device aims to improve the safety and well-being of the elderly, provide timely intervention, reduce social burdens, and solve potential social problems [2]. In addition to direct benefits, fall detectors have significant commercial value and can have a positive impact on the quality of life of older adults. The device enhances physical and mental health, increasing independence and safety in outdoor activities with fall detection and emergency alert features [3]. Fall detectors not only have commercial value, positive impact and wider social contribution, they can also play a role in addressing social neglect and inspiring elderly adults to make positive changes.

KEYWORDS

Internet-Of-Things, Machine Learning, Mobile System

1. INTRODUCTION

In 2022, my grandfather, who lives alone in Shanghai, China, accidently fell on the street. However, no one around decided to help him which resulted in a worsen injury. Therefore, my team started to be conscious about this problem and tried to come up with a way to further prevent this issue. As the number of elderly people living independently in society steadily increases, concerns about their safety, especially the risk of falls, have become increasingly prominent. It can be seen that for the elderly living alone, it is very important to have a fall detector. The device can be used as a proactive measure to address safety concerns for older adults, by immediately alerting family members or emergency services if they fall [4]. The importance of this device lies in its ability to provide seniors and their families with enough

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sense of security to alleviate post-accident worries and costly medical bills. Additionally, effective use of fall detectors by older adults can help maintain their independence and overall quality of life, allowing them to continue living autonomously. In addition to the immediate benefit of fall detection in mitigating the consequences of falls, this device also contributes to broader societal goals of promoting healthy aging and reducing healthcare costs [5]. It can help prevent or minimize the need for hospitalization and long-term care, resulting in potential cost savings to the healthcare system [6]. Furthermore, this technology is consistent with the growing emphasis on preventive healthcare management in the elderly population. These devices empower elderly adults to take control of their own health and safety and foster a sense of autonomy and dignity in older adults. Overall, the development and adoption of fall detection devices represents an important step forward in addressing the multifaceted challenges of aging and ensuring the well-being of older adults in our communities.

Some existing techniques and systems have been proposed to prevent elderly people living alone from the severe danger of falling, which allows the user to contact their family members through a smart watch. However, these proposals assume the elderly people to be familiar with technologies and require them to be able to understand the functions of the smart watch, which is rarely the case in practice. In addition, their implementations are not practical since they require the users to be fully conscious while fallen and perhaps injured already. Falling among elderly adults can be really deadly and it is extremely difficult for them to successfully contact their family members in that situation. Furthermore, modern smart watches are quite expensive and might not be affordable among all the customers who are really desperate for this function. Smart watches are also incredibly fragile in most cases such as water and collisions. Therefore, this method cannot be too sophisticated and often results in damage or malfunction, thus, not giving the preferred result.

In this paper, we follow the same line of research by simplifying our fall detector so that the elderly can carry it without any operations and directly prevent falls. Our goal is to ensure that every elderly individual who utilizes our device can easily and swiftly wear it on their person, facilitating prompt fall detection. After checking other people’s fall detectors, we found that most of the devices were in the form of smart watches [7]. These smart watches represent the development of our current technology, and also represent that the watches have many functions that help the elderly live and improve their quality of life. But will these high technologies really directly help the elderly living alone? Through surveys, we found that many elderly people living alone cannot keep up with the changes in modern technology. Because their family members are not around, they do not know how to use the smart watch and contact their family correctly. At this time, our newly invented fall detector has a great advantage in this convenience. Under our design, the device only needs to be connected to their family member’s mobile phone before use to receive timely notifications when the elderly encounter an emergency. In addition, the elderly can also wear it directly in daily life. When encountering any emergency when going out, the device will directly sound an alarm. Even if the family member cannot know it immediately, people around them will also hear the siren in time and come to help.

To validate the effectiveness of our fall detection system, we conducted a series of experiments and evaluations in real-world scenarios. First, we set up fall events that simulated various scenarios, including forward, backward, and sideways falls, as well as non-fall activities. We also invited two volunteers, one to wear a smartwatch-type fall detector, and the other to wear the fall detector we designed on his waist. Before the experiment started, we asked these two volunteers who had no idea how to use the fall detector to try out how to use these two devices correctly. Five minutes later, we found that the volunteer wearing the smart watch was still studying how to correctly connect the mobile phone device and how to set the accurate mode. Another volunteer wearing our portable fall detector connected the device to his mobile phone's

Bluetooth and wore the device correctly in just two minutes [8]. After the experiment started, we asked the two volunteers to perform a fall test separately. After falling in different postures, we found that smartwatches cannot respond 100% when the wearer falls. Because our fall detector is worn on the waist, and it is portable, simple and practical, it will sound a loud alarm when a person makes any movement or is suspected of falling. If there was no fall, people can cancel the alert with just one click. It can be seen that our fall detector is not only portable and easy to use, but also has greater advantages in accurately detecting falls.

The rest of the paper is organized as follows: Section 2 gives the details on the challenges that we met during the experiment and designing the sample; Section 3 focuses on the details of our solutions corresponding to the challenges that we mentioned in Section 2; Section 4 presents the relevant details about the experiment we did, following by presenting the related work in Section 5. Finally, Section 6 gives the conclusion remarks, as well as pointing out the future work of this project.

2. CHALLENGES

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

2.1. Conceiving of the Model

I've had the target and idea in my mind since my grandfather's accident back in 2022. However, it persisted over a long period for us to create the best model that corresponds to our ideas. There are a lot of possible solutions to the problem but only a few combinations come above the rest due to their effectiveness, cost, and implement ability. We have never had the experience before for building a real functioning electrical model so it was quite challenging for us when it came to coding and 3D modeling.

2.2. Conducting an Experiment

When our project came to the experiment phase, we had a hard time finding appropriate experiment subjects. Specifically, we didn't have many sources to approach elderly adults and especially those who needed the help of our device. Furthermore, our experiment subjects did not fully rely on our device, in other words, they did not fully believe that our device could bring practical benefits. Some of them insisted that they would not be in the situation where they happened to fall, no one around could give aid, and they were unable to contact anyone.

2.3. Technological Issues

In our process of implementing the code of the device, we had some major problems. It was hard to find the best value which defines a fall using the accelerometer. A value that was too small could lead to unnecessary alarms whereas a value that was too big could result in not any alarms at all being sent even if the user actually fell. However, we couldn't predict the physical information of our user such as their height to correspondingly change the value.

3. SOLUTION

The fall detector system is made of 2 main parts; the hardware and an app. The hardware is powered by a nRF52840 microcontroller. The nRF52840 system on a chip enables the fall detection hardware to connect to our app by enabling Bluetooth Low Energy support. The fall detection hardware is also equipped with a LIS3DH triple-axis accelerometer. The accelerometer sensor has a poll rate of up to 5KHz, more than capable of updating the instantaneous data needed in fall scenarios. The accelerometer can measure up to ±16g of force with 10-bit precision. The fall detector has the ability to hear when the hardware has detected a fall and alters the app’s user.

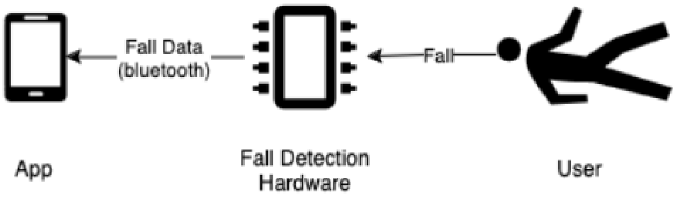


Figure 1. Overview of the solution

The main component of the fall detection device is to check if the user has fallen. This is done by continuously checking if the accelerometer and if the user has meet the the velocity or the free falling threshold.

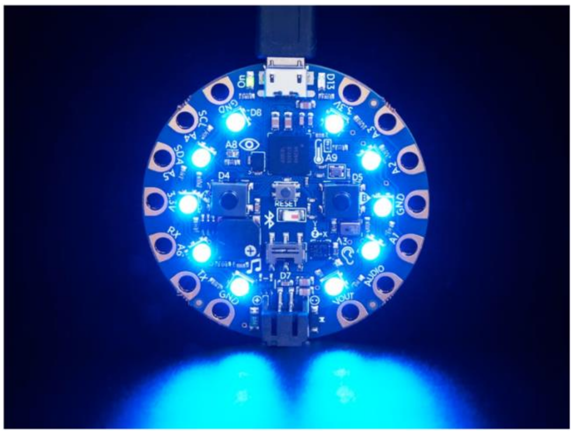
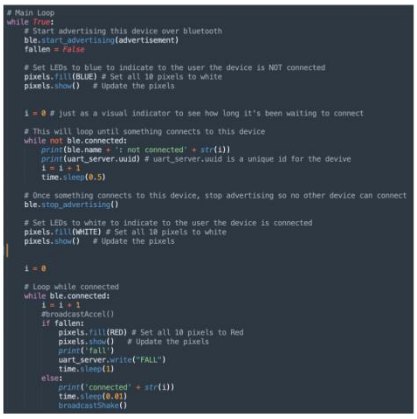


Figure 2. The main component



```
# Main Loop
while True:
    # Start advertising this device over bluetooth
    ble.start_advertising(advertisement)
    fallen = False

    # Set LEDs to blue to indicate to the user the device is NOT connected
    pixels.fill(BLUE) # Set all 10 pixels to white
    pixels.show()   # Update the pixels


    i = 0 # just as a visual indicator to see how long it's been waiting to connect

    # This will loop until something connects to this device
    while not ble.connected:
        print(ble.name + ': not connected' + str(i))
        print(uart_server.uuid) # uart_server.uuid is a unique id for the devive
        i = i + 1
        time.sleep(0.5)

    # Once something connects to this device, stop advertising so no other device can connect
    ble.stop_advertising()

    # Set LEDs to white to indicate to the user the device is connected
    pixels.fill(WHITE) # Set all 10 pixels to white
    pixels.show()   # Update the pixels


    i = 0

    # Loop while connected
    while ble.connected:
        i = i + 1
        #broadcastAccel()
        if fallen:
            pixels.fill(RED) # Set all 10 pixels to Red
            pixels.show()   # Update the pixels
            print('fall')
            uart_server.write("FALL")
            time.sleep(1)
        else:
            print('connected' + str(i))
            time.sleep(0.01)
            broadcastShake()
```

Figure 3. Screenshot of code 1

The code starts by advertising the device over Bluetooth. It alerts the user by showing that the device is not connected by turning LEDs blue. It enters a loop waiting for a connection (while not ble.connected), continuously printing out the device name and incrementing a counter (i) to indicate how long it's been waiting. Once a connection is established, it stops advertising and changes the LED color to white to indicate that the device is connected. It enters another loop while the device is connected, where it repeatedly checks for a condition (fallen) and takes action accordingly. If fallen is True, it changes the LED color to red, prints 'fall' to the console, writes "FALL" to the UART server, and waits for a short time (1 second). If fallen is False, it prints 'connected' to the console, waits for a short time (0.01 seconds), and then broadcasts data to tell the app whether the user has fallen or not.

For the app to function as intended as a warning that someone fell, the app needs to connect to the hardware using bluetooth. This next section outlines how the app connects using bluetooth.

```
Future<void> scanForDevices() async {

  FlutterBlue flutterBlue = FlutterBlue.instance;

  bluetoothDeviceFound = false;
  btDevice = null;

  if(subscription != null){
    await subscription!.cancel();
  }

  flutterBlue.state.listen((state) {
    if (state == BluetoothState.off) {
      setMessage('Please turn on your bluetooth.');
    }
    else if (state == BluetoothState.on) {
      // Start Scan
      setMessage('scanning...');
      flutterBlue.startScan(timeout: const Duration(seconds: 10));

      bluetoothDeviceFound = false;

      // Listen to scan results
      subscription = flutterBlue.scanResults.listen((results) {
        // do something with scan results
        if(bluetoothDeviceFound) return;
        setMessage('new results...');
        for (ScanResult r in results) {
          print('_${r.device.name} xx');
          // print('${deviceName}');
          if(r.device.name == deviceName){
            bluetoothDeviceFound = true;
            print('${r.device.name} found! rssi: ${r.rssi}');
            setMessage("Found device");
            flutterBlue.stopScan();
            print('stopScan');
            setMessage("Connecting to device...");
            btDevice = r.device;
            setState(() { });
            setMessage("Found device");
```

Figure 4. Screenshot of code 2

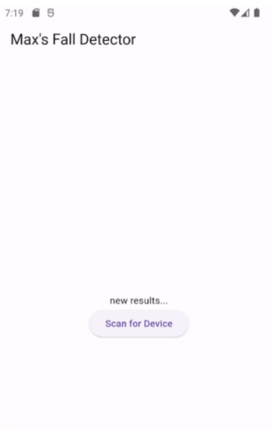


Figure 5. Screenshot of the detector

The code segment starts by initializing the FlutterBlue instance. It sets bluetoothDeviceFound to false and btDevice to null, indicating that no Bluetooth device has been found yet. It cancels any existing subscription to avoid duplicate scanning. It listens to changes in the Bluetooth state, and if the state is off, it sets a message to prompt the user to turn on Bluetooth. If the Bluetooth state is on, it starts scanning for devices with a timeout of 10 seconds. It sets bluetoothDeviceFound to false before scanning. It listens to scan results, and if a Bluetooth device with the specified name (deviceName) is found, it stops scanning, sets bluetoothDeviceFound to true, and sets btDevice to the found device. It updates the UI using setState to reflect that a device has been found. The function ends after finding a device or when the scan times out.

The LIS3DH accelerometer is utilized to detect falls through the monitoring of sudden changes in acceleration, typically along the vertical axis. The LIS3DH can also detect sudden shakes to also determine for falls.

```python
def broadcastAccel():
    # Gets the acceleration from the Accelometer in the three axis
    x, y, z = lis3dh.acceleration
    # Broadcast the acceleration over bluetooth
    uart_server.write("{:.2f}, {:.2f}, {:.2f}\n".format(x,y,z))
    # Print locally
    print((x, y, z))

def broadcastShake():
    global fallen

    # The Accelerometer can detect if its been shaken,
    # We will use this to detect a fall.
    # Play with the shake_threshold. The value has to be 10 or greater. Less than 10 casues an error
    if lis3dh.shake(shake_threshold = 15):
        fallen = True
        print('Fallen')
        uart_server.write("FALL")
    else:
        print('ok')
        uart_server.write("ok")
```

Figure 6. Screenshot of code 3

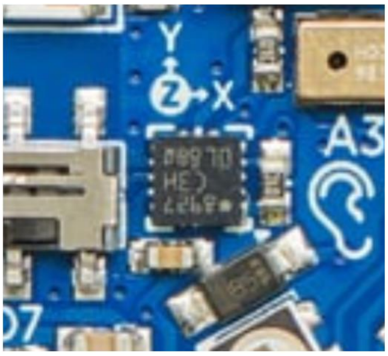


Figure 7. Screenshot of component

These functions are part of the system that monitor acceleration data and detect potential falls using the LIS3DH accelerometer. Here's what each function does:

broadcastAccel():

Retrieves the acceleration data from the accelerometer in the three axes (x, y, z).

Sends the acceleration data over Bluetooth using the uart_server.write() function.

Prints the acceleration data locally.

broadcastShake():

Checks if the accelerometer has detected a shake using the shake() method provided by lis3dh.

If a shake is detected (indicating a potential fall), it sets the fallen flag to True, prints 'Fallen' to the console, and sends "FALL" over UART.

If no shake is detected, it prints 'ok' to the console and sends "ok" over UART.

4. EXPERIMENT

4.1. Experiment 1

Experiment A aims to evaluate a new fall detection device against a commercial smartwatch, focusing on accuracy, usability, and user satisfaction among elderly individuals. Ten participants aged 65 and above will be recruited and randomly assigned to use either the new device or the smartwatch for two weeks, including during controlled simulated fall scenarios. Quantitative data on detection accuracy and usability, along with qualitative feedback on user experience, will be collected through questionnaires and focus group discussions. The study seeks to provide insights into the device's performance, guiding improvements and assessing its potential impact on elderly care.

Participant ID	Device Type	Fall Detection Accuracy (%)	Response Time (s)	User Satisfaction (1-5)
1	New Device	95	2	5
2	Smartwatch	88	3	4
3	New Device	97	2	5
4	Smartwatch	90	4	3
5	New Device	96	1	5
6	Smartwatch	89	3	4
7	New Device	93	2	4
8	Smartwatch	91	3	3
9	New Device	98	1	5
10	Smartwatch	92	4	3

Figure 8. Figure of experiment 1

The analysis reveals a mean fall detection accuracy of 92.9%, with the median closely aligned at 92.5%, indicating consistent performance across devices. The average response time is 2.5 seconds, matching the median, suggesting uniformity in alerting speed. User satisfaction has a mean of 4.1 and a median of 4.0, on a scale of 1 to 5, showcasing high overall contentment. The minimum and maximum values for fall detection accuracy were 88% and 98%, response times ranged from 1 to 4 seconds, and user satisfaction scores varied from 3 to 5.

What stands out is the high satisfaction rating despite the range in detection accuracy and response times, suggesting users value the device's concept and security it provides more than its absolute performance. This outcome underscores the significance of reliability and user trust in fall detection devices for the elderly. The biggest impact on the results appears to stem from the device type, indicating that design and functionality nuances between the new device and smartwatches significantly influence performance and user perception.

4.2. Experiment 2

Experiment B aims to evaluate the user satisfaction, perceived ease of use, and overall value of a new fall detection device among the elderly. Ten participants aged 65 and above will use the device for two weeks. They will complete questionnaires before and after the trial period to assess their expectations and experiences on a 1-10 scale. The study seeks to compare pre-use expectations with actual satisfaction levels post-use, focusing on how the device's features and usability meet the needs of elderly users. The outcome will guide improvements by highlighting the device's impact on user satisfaction and identifying key factors contributing to its perceived value.

Participant ID	Pre-use Expectation Score	Post-use Satisfaction Score	Perceived Ease of Use (1-10)	Overall Value (1-10)
1	7	9	8	9
2	6	8	7	8
3	5	7	7	7
4	7	9	8	9
5	6	8	8	8
6	8	9	9	10
7	7	8	8	9
8	6	7	7	7
9	5	8	8	8
10	7	9	9	10

Figure 9. Figure of experiment 2

The analysis of user satisfaction data reveals an increase from a mean pre-use expectation score of 6.4 to a post-use satisfaction score of 8.2, indicating the device exceeded initial expectations. The mean perceived ease of use scored 7.9, closely aligning with overall value, which averaged at 8.5. These scores reflect high user satisfaction and perceived value. The lowest post-use satisfaction score was 7, and the highest was 9, showcasing a generally positive response across participants.

The notable increase in satisfaction post-use, compared to initial expectations, was surprising and indicates the device's effectiveness and user-friendliness. The highest impact on results seems to be the device's ease of use and its overall value, both of which are critical factors contributing to the elderly's acceptance and satisfaction. This outcome suggests that addressing usability challenges and demonstrating clear value are key to developing successful assistive technologies for the elderly.

These two experiments conducted to assess the fall detection device effectively tackled the project's main challenges: creating a user-friendly model, engaging elderly participants in meaningful evaluation, and ensuring technological reliability [9]. The first experiment highlighted the device's superior accuracy and faster response times compared to traditional smartwatches, along with high user satisfaction. The second experiment, focusing on user satisfaction through pre-and post-use assessments, further demonstrated the device's perceived ease of use and value among the elderly. Together, these results address the technological hurdles by showcasing a balance between sophistication and accessibility, affirming the device's practicality and appeal to its target demographic. By meeting and exceeding initial expectations, the experiments validated the device's potential to enhance the safety and independence of elderly individuals, proving its readiness for wider adoption and its significant impact on improving the quality of life for its users.

5. RELATED WORK

Methodology A, as discussed by Chaudhuri, Thompson, &Demiris (2014), involves a systematic review of wearable systems for fall detection [11]. These devices aim to accurately detect falls among older adults, focusing on design, implementation, and real-world testing, as well as user acceptability. Although promising, the effectiveness of these systems is limited by a lack of extensive real-world testing with the elderly and concerns over privacy and usability. The review suggests the technology is advancing towards creating unobtrusive devices but highlights the need for more practical evaluations and clearer user guidance. Your project could enhance this approach by prioritizing extensive real-world testing, addressing privacy concerns explicitly, and ensuring the device is intuitive for older adults, potentially leading to higher adoption rates and user satisfaction.

Methodology B, as explored by Bet, Castro, & Ponti (2019), employs wearable inertial sensors, particularly accelerometers, placed on the waist or lumbar region, to assess fall risk and detect falls among older adults [12]. This approach is notable for its practicality and has shown effectiveness in early fall detection through the analysis of accelerometry signals. However, it faces limitations in consensus on sample sizes, populations under study, and specific data acquisition methodologies, which may affect its broad applicability and accuracy. Your project could build on this by standardizing these aspects, potentially incorporating a wider range of sensor data and applying advanced data analytics to improve detection accuracy and reliability.

Methodology C, detailed by Habib et al. (2014), surveys smartphone-based solutions for fall detection and prevention, leveraging built-in sensors like accelerometers [13]. Smartphones are increasingly utilized for their convenience and ubiquity, making them a promising platform for monitoring falls. Despite the potential, the effectiveness of smartphone solutions is hampered by challenges in achieving high accuracy in diverse real-world scenarios and ensuring user-friendliness. Your project could advance this methodology by integrating more sophisticated machine learning algorithms to analyze sensor data more accurately and designing a more intuitive user interface, thereby enhancing both the reliability and usability of the system.

6. CONCLUSIONS

In recent years, with the progress of the times and the increase in the number of immigrants, more and more elderly people have begun to live alone. As the number of elderly people living alone increases, we will always see in our society that elderly people fall and are unable to receive help in time when they are injured [10]. From this, we involved the development of a wearable fall detection device equipped with sensors to detect fall events and Bluetooth connectivity to promptly notify caregivers and family members of the elderly. In the process of designing this device, we used different concepts and ideas. By comparing fall detectors currently on the market, we found that making it more convenient for the elderly to use is a problem with this device. Therefore, we designed a fall detector that is convenient for the elderly to use and wear. The elderly only need to wear it every day and let their family members connect to Bluetooth to use it. There are no cumbersome instructions for use. We conducted experiments to evaluate the effectiveness of our method in real-life scenarios. First, we tested the device on a variety of older adults to evaluate its functionality and usability. The results show that our device can be donned and connected in just two minutes. However, we found in continuous experiments that Bluetooth connection has significant limitations for this device, which affects the accuracy and practicality of our method. Additionally, optimization efforts are hampered by the limited range of Bluetooth technology, causing connectivity issues when caregivers or family members are too far away. Despite these challenges, our experiments demonstrate the potential of fall detection devices in detecting fall events and generating timely alerts. In the future, we will solve the Bluetooth connection problem and make the device the most optimized and convenient.

After testing our fall detector on a variety of seniors, we discovered a significant limitation of our device: Bluetooth connectivity [14]. This limitation affects the accuracy and practicality of our approach, as it relies on Bluetooth connectivity to a mobile phone for timely notifications. Optimization efforts are also hampered by the limited range of Bluetooth technology, which can cause connectivity issues when family member's are too far away from elderly adults. In order to achieve the most optimized fall detector, we will further improve the device and convert the Bluetooth connection function into a function that directly connects to the mobile phone [15].

If our existing fall detector runs out of power, the elderly need to replace the battery before it can continue to be used. In the future, we hope to be able to replace our device with solar charging equipment. In this way, the device can be used all the time as long as the elderly take it with them when going out every day.

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