Wearable Fall Detection and Prevention Device

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***Abstract*: The development of wireless handheld devices in fall detection using IoT technology plays a vital role in the improvement of healthcare. According to World Health Organization, 28–35% of the population over the age of 64 experience at least one fall every year, while fall-related injuries and hospitalization rates are expected to increase on average by 2% per year until 2030. Morbidity and mortality provoked by falls are closely connected to the rapidness of the medical response and first aid treatment after the incident. Consequently, the analysis of cost-effective and automatic Fall Detection Systems (FDSs) has become a relevant research topic during the last years. This project focuses on a lightweight waist-mounted gadget that monitors the user's activity. These systems typically use acceleration signals to detect sudden changes in movement or orientation, such as an abrupt drop in altitude or a change in the angle of the body. An airbag is developed to protect the individual by automatically inflating the airbag that absorbs the shock of the fall, reducing the impact on the human body, and preventing fractures and other injuries. A Relay board is mounted with the circuit which helps to inflate the airbag. When a fall is detected, the system automatically sends an alert to a caregiver's smartphone or a monitoring center. Also, an alarm is used when a fall event occurs to alert bystanders until the user can sit up or rise up. MEMS Accelerometer is used for rapid fall recognition and the GSM module is employed to send alert notifications. The key characteristics of this fall sensor are the new fall-sensing methodology, which uses a triaxial, single-unit accelerometer and angular velocity sensor to sense the event of a fall and thus this system can provide an added layer of safety and peace of mind for the elderly individuals and their caregivers, helping to ensure that help can be summoned quickly in the event of fall.**

***Keywords*: IoT, Fall Detection System (FDS), GSM, Airbag, MEMS accelerometer, Sensor.**

1. Introduction

The fall is characterized as a minor mishap, such as tripping over a rug or sliding on a damp floor, which can drastically alter the existence. Falls in elderly people are a big danger to their independence. Falls often happen when an individual's capacity for compensating is compromised by numerous impairments. The second most common reason for unintentional injury fatalities globally is falling. The majority of deadly accidents occur in adults over the age of 60. Each year, there are 37.3 million accidents that are serious enough to need medical treatment. Education, training, safer environments, prioritizing fall-related research, and the creation of efficient laws should all be emphasized in prevention tactics. Many elderly people experience bone fractures each year as a result of falls. A fractured bone can initiate more severe health issues in elderly people, which can result in long-term impairment. Many accidents, though, can be avoided. For instance, you can avoid falls by exercising, managing your medicines, getting your eyesight examined, and making your house safer. Even if they have never fallen before, many elderly people are afraid of falling. They might refrain from going for walks, buying, or engaging in social activities as a result of this dread. However, remaining active is crucial to maintaining your body's health and truly works to reduce the risk of falling. Therefore, resist the urge to stay inactive out of dread of collapsing. To feel more at ease remaining active, learn about what causes falls and how to reduce your risk of stumbling.

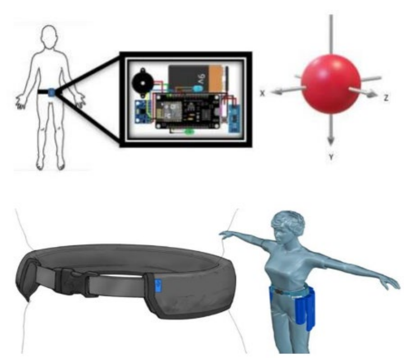

Fig. 1. Proposed system to detect fall in older adults

Although many people have no symptoms before a fall, some have dizziness or other symptoms. It's possible that you don't have as good hearing, vision, or reactions as you did when you were younger. Your equilibrium may be affected by certain illnesses, such as diabetes, heart disease, or issues with your muscles, feet, thyroid, or blood vessels, which may cause you to trip and fall. Falls may also be more likely in conditions like incontinence that force hurried trips to the loo. Elderly people who have moderate cognitive impairment or specific kinds of dementia are more likely to stumble. Risk factors for falling include postural hypotension, issues with balance and gait, and age-related loss of muscle mass (sarcopenia), which causes an excessive decrease in blood pressure when you get up from laying down or seated. Some medicines have adverse effects, such as confusion or dizziness, which can raise a person's risk of stumbling. You are more likely to stumble if you take more medicines. Falls can also occur as a result of safety hazards in the house or neighborhood. Regular exercise strengthens muscular movements and enhances the body, tendons, and

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joints limber. Walking or ascending steps, which are light weight-bearing exercises, may help slow bone loss caused by osteoporosis, a condition that makes bones brittle and more likely to break. Balance and muscular power can be improved through yoga. Resistance bands help to maintain strength and muscle mass without overdoing it. Research indicates that training programs using elastic tubes are a practical, effective means of increasing strength in adults over the age of 65. Low blood pressure might also be the reason for falls. Treating blood pressure can also help people, especially elderly people to prevent falls. They can happen at home, in hospitals, or in long-term care facilities. Falls raise the possibility of severe injuries, ongoing discomfort, permanent impairment, and loss of independence. Even if there were no bodily injuries, an accident can still result in psychological harm. Due to their fear of falling again, people who fall frequently find that their everyday tasks and self-care are reduced. Their mobility, balance, and health are all hampered by this habit, which also reduces social contact and raises melancholy. With age, the fatality rate from accidents gradually rises. Injuries from falls resulted in 36% of fatalities in men and 57% of deaths in women aged 65 and over.

Table 1
Factors contributing to fall scenario

Category	*Scenario*
Fall Forward	Walked - fell forward- ended face-down
Fall Backward	Walked - fell backward - ended laying on the floor
Fall to the left	Walked - fell to the left - ended with laying on the floor
Fall to the right	Walked - fell to the right - ended with laying on the floor

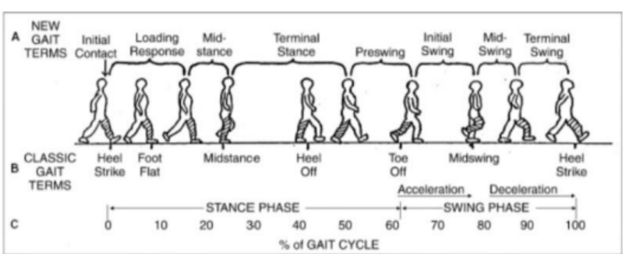


Fig. 2. Walking pattern (Gait cycle)

When someone walks with a spastic gait, they drag their feet. When walking, someone with this type of gait may also appear to be very stiff. This caused the entire body to collapse when hit by an object. A person with inwardly bending legs frequently walks with a scissors gait. Legs are crossed and bent backward in this type. The crisscross movement may resemble the opening and closing of a pair of scissors. This caused a fall to the side or back. When someone walks with their toes pointed down, this is called a steppage gait. The feet frequently scrape the floor as the person moves forward. The result was a forward fall. As the name implies, a person who walks with a waddling gait sway from side to side. Waddling involves swinging the body and taking small steps. A person who walks with their head and neck thrust forward is said to have a propellant gait. The individual may seem to be stubbornly maintaining a slouched posture. Major reasons for falling forward include the above two situations.

Each stride includes an ever-changing alignment between the body and the supporting foot during stance and the selected advancement of the limb segments in the swing in order to deliver the fundamental functions necessary for walking. The hip, knee, and ankle undertake a variety of motion patterns as a result of these responses. There are eight practical patterns in each stride. Technically, these are subphases because the gait cycle's fundamental divisions are stance and swing, but in everyday speech, we refer to the functional intervals as phases. The varied movements that occur at the distinct joints are more precisely identified as having a functional purpose when a person's walking pattern is broken down into phases. The phases of gait also offer a way to link the simultaneous movements of the various joints into predictable patterns of the total limb function. This method is particularly crucial for understanding the walking pattern function. Each phase of the gait cycle has the different relative importance of each joint's motion in relation to the others. Additionally, because the functional need has changed, a posture that is adequate at one time in the gait cycle may indicate dysfunction at a later stage of the stride. Timing and joint angle are therefore highly important. This latter element makes gait analysis more difficult. Each of the eight gait phases has a functional aim, and achieving this objective requires a certain pattern of selected synergistic motion. The sequential arrangement of the stages also enables the limb to carry out three fundamental duties. These are limb advancement, single limb support, and weight acceptance (WA). The stance time and the first two gait phases are used for weight acceptance. (initial contact and loading response). The following two phases of gait are continued in stance with single limb support. (mid-stance and terminal stance). Limb advancement starts at the last stance phase (pre-swing), and continues throughout the three swing phases. (initial swing, mid swing, and terminal swing). Each stride in the gait cycle is the major consideration for creating a database describing the walking pattern of different people. This database obtained from deep learning is used as the input factor for the fall detection algorithm.

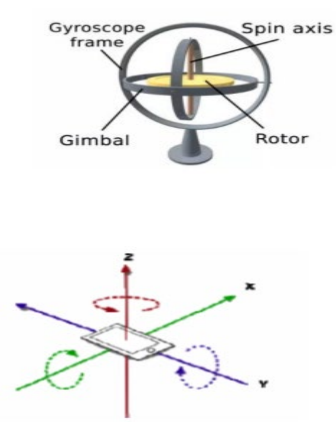


Fig. 3. Axis of accelerometer and gyroscope

The parameters used in analyses are similar to those proposed in previous studies. The total sum acceleration vector, Acc, containing both static and dynamic acceleration components, is calculated from sampled data using

$$\mathbf{Acc} = \sqrt{(A_x)^2 + (A_y)^2 + (A_z)^2} \quad (1)$$

where, A_x, A_y, A_z an are the accelerations (g) in the x, y and z directions. Similarly, angular velocity is calculated from sampled data as indicated in the following:

$$\boldsymbol{\omega} = \sqrt{(\omega_x)^2 + (\omega_y)^2 + (\omega_z)^2} \quad (2)$$

Where W_x, W_y and W_z are angular velocities in x, y and z directions. When stationary, the acceleration magnitude, Acc, from the triaxial accelerometer is constant (+1 g), and angular velocity is 0°/s. When the subject falls, the acceleration is rapidly changing and the angular velocity produces a variety of signals along the fall direction. Critical thresholds in the acceleration and angular velocity are then used for determining a fall event. These critical thresholds are defined and derived as follows. (i) Lower fall threshold (LFT): local minima for the Acc resultant of each recorded activity are referred to as the signal lower peak values (LPVs). The LFTacr the acceleration signals is set at the level of the smallest magnitude lower fall peak (LFP) recorded. (ii) Upper fall threshold (UFT): local maxima for the Acc resultant of each recorded activity are referred to as the signal upper peak values (UPVs). The UFT for each of the acceleration (UPVacc) and the angular velocity (UFTgyro) signals are set at the level of the lowest upper fall peak (UFP) recorded for the Acc respectively. The UFTacc is related to the peak impact force experienced by the body segment during the impact phase of the fall. Fall detection algorithms using accelerometers are normally divided into two groups, one based on LFTacc comparison and the other based on UFTacc comparison. Although past research has achieved some significant results, accuracy of these strategies is still below desired level used LFTacc and UFTacc and found the sensitivity and specificity of performance to be 83.33% and 67.08%, respectively. In this study, we use both LFTacc and UFTacc in combination with UFTgyro the for-fall detection. We determine the LFT and UFT for both the acceleration and angular velocity based on collected experimental data. First, the instantaneous acceleration magnitude, Acc, is computed and compared to the LFTacc. When Acc falls below the LFTacc threshold, data from the next 0.5 s, period referred to as fall window, is compared to the UFT for both the acceleration and angular velocity vector. The fall window period was obtained from the literature. Within the fall window, if both magnitudes of acceleration and angular velocity are above the UFTgyro and UFTacc, respectively, then a fall is detected. If only one or neither is observed, a fall is not indicated.

2. Methodology

A. *Falls in the Elderly*

The aging process is a process that occurs naturally and occurs continuously in every human being. It is undeniable that every time that passes every human being will continue towards the aging process which can be referred to as the elderly [6]. Law No. 13 of 1998 explains that the elderly is someone who reaches the age of 60 years. This stage of aging is also accompanied by a process of physical, mental, and social decline so that carrying out daily routines becomes constrained. One of the changes in the elderly is related to the risk of falling. Falling is slid.ing down at a certain speed due to the influence of the earth's gravity.

Three factors cause the risk of falling in the elderly based on the physical decline [7], namely:

1) *Sense system*

Specific changes in the sensory system in the elderly occur in vision and hearing. In the visual system where the lens of the eye loses elasticity and stiffens. The muscles that support the lens weaken and the acuity of vision and accommodation at distance or near is reduced, requiring the elderly to wear glasses. While the hearing system is impaired due to loss of ability to hear in the inner ear, especially in high-pitched sounds or tones, the sound heard is unclear and difficult to understand, 50% occurs in people over 60 years of age. This decrease in the sensory system will increase the likelihood of falling.

2) *Musculoskeletal system*

Changes in the musculoskeletal system in the elderly are related to several parts, namely connective tissue (collagen and elastin), cartilage tissue, bones, muscles, and joints. This factor plays a major role in the occurrence of falls in the elderly. Musculoskeletal disorders will cause disturbances in gait, due to stiffness of the connective tissue, reduced muscle mass, slowed nerve conduction, and decreased vision. This will result in decreased range of motion joint (ROM), decreased muscle strength, increased reaction time, and body sway. All of these changes result in slowness of movement, short steps, decreased rhythm, feet do not tread firmly, and tend to be easily wobbly, difficult, or slow to anticipate when disturbances occur such as slips, trips, or sudden events that can result in falls.

3) *Nervous system*

The nervous system undergoes anatomical changes where there is a decrease in coordination and the ability to perform daily activities. This aging process causes a decrease in sensory perception and motor responses in the central nervous system.

B. *Overall System Block Diagram*

In the IoT-based fall detection system in the elderly, in the first study, you have to make a program on the Arduino IDE software, then upload it to the Node MCU ESP8266 board and open the serial monitor on the Arduino IDE to find out the IP Address that will be used to access the Server Web.[9] The following is a blog diagram of an IoT-based fall detection system for the elderly.

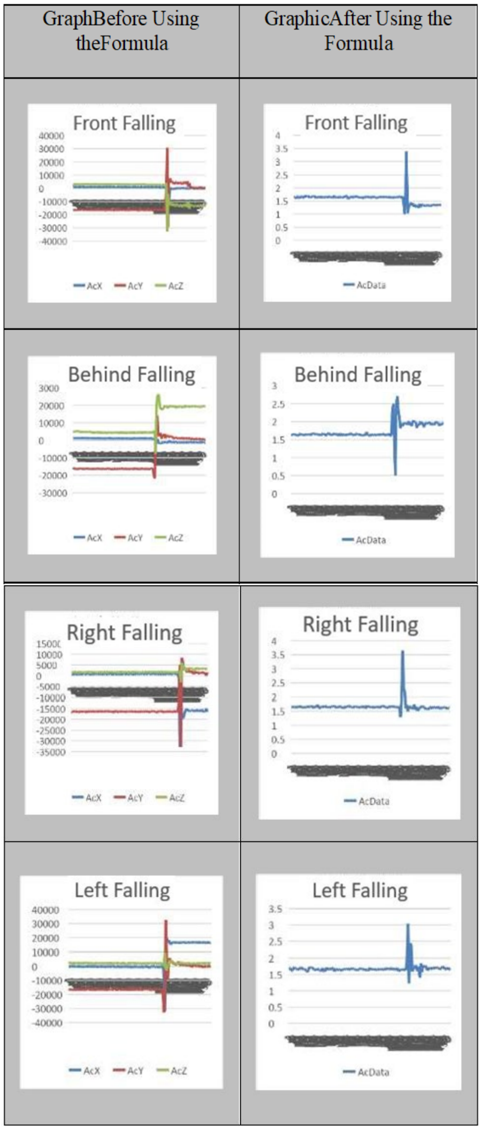


Fig. 4. Graph of falling scenarios before and after using the formula

The system is divided into three blocks, namely the IoT Module block, the Web Server Block, and the Supervisory block. In the IoT Module block, which is a tool that will be used by the patient to detect movement in the patient, on the device, there is a Node MCU ESP8266 as a microcontroller, the MPU6050 GY521 module as a sensor accelerometer, and a buzzer for notifications. On the Web Server block, it uses firebase made by google. And on the User block, it uses an application installed in the application that will provide notifications of activities carried out by the patient and notification of danger when the patient falls.

C. Overall System Testing

In this fall detection test, the test is an accelerometer carried out using a threshold. The threshold is a point that is used to determine the condition of falling on the user. The threshold is determined by testing the data when a fall occurs. Testing of fall detection data includes falling forwards, backward, to the right, and the left.

Acceleration = AcX2+AcY2+AcZ2

3. Materials

A. Relay Board

The switching mechanism is carried out with the help of the electromagnet. The main operation of a relay comes in places where only a low-power signal can be used to control a circuit.

Fig. 5. Two relay board

B. MEMS Accelerometer

MEMS accelerometer is used whenever there is a need to measure linear motion, either movement, shock or vibration but without a fixed reference. They measure the linear acceleration of whatever they attached to. Acceleration is measured in m/s^2, but the convention for accelerometers is in ‘g’ or unit of gravity, 1g being 9.81m/s^2.

Fig. 6. MEMS accelerometer

C. Arduino

Arduino ATMEGA-328 microcontroller consists of 14 input and output analog and digital pins (from these 6 pins are considered to be a PWM pin), 6 analog inputs, and the remaining digital inputs. A power jack cable is used to connect the Arduino board to the computer. Externally battery is connected to the Arduino microcontroller for the power supply.

D. Power Supply Unit

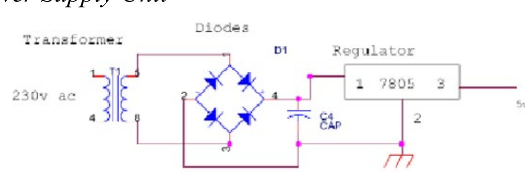


Fig. 7. Power supply unit

The power supply unit consists of the following components:

1) Step-Down Transformer:

The step-down transformer is used to step down the main supply voltage from 230V AC to a lower value. This 230 AC voltage cannot be used directly; thus, it is stepped down.

2) Rectifier Unit:

The rectifier circuit is used to convert the AC voltage into its corresponding DC voltage. There are three types of rectifiers:

half-wave, full-wave, and smoothing. Half-wave rectification can be achieved with a single diode in a one- phase supply, or with three diodes in a three-phase supply. Full-wave rectifiers use a diode bridge, made of four diodes, like this. The diodes working in pairs, and as the voltage of the signal flips back and forth, the diodes allow the current to always flow in the same direction for the output. If we feed our AC signal into a full wave rectifier, we'll see both halves of the wave above 0 Volts, and the voltage will be lower by two diode drops, or 1.2 Volts.

a) Bridge Rectifier

A bridge rectifier is an arrangement of four diodes in a bridge configuration that provides the same polarity of output voltage for either polarity of input voltage. It is used for the convers on of alternating current (AC) input into rectifier current (DC) output, resulting in lower cost and we as compared to a center-tapped transformer design.

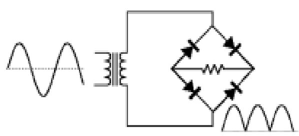


Fig. 8. Bridge rectifier

1) Input filter:

Capacitors are used as filter. The ripples from the DC voltage are removed and pure DC voltage is obtained. And also, these capacitors are used to reduce the harmonics of the input voltage. The primary action performed by capacitor is charging and discharging. It charges in positive half cycle of the AC voltage and it will discharge in negative half cycle. So, it allows only AC voltage and does not allow the DC voltage. This filter is fixed before the regulator. Thus, the output is free from ripples. The basic quantities which describe this circuit are similar to those used for the Low Pass Filter. In effect, this circuit is just a simple low-pass filter with the components swapped over.

$$\tau = R_1 C_1$$

The action of the circuit can also be described in terms of a related quantity, the *Turn over Frequency, f_0*, which has a value,

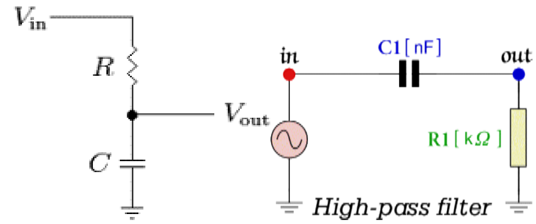
$$f_0 = \frac{1}{2\pi\tau} = \frac{1}{2\pi R_1 C_1}$$

As a result, any sudden change in the input voltage produces a similar sudden change on the other side of the capacitor. This produces a voltage across the resistor and causes a current to flow thorough it, charging the capacitor until all the voltage falls across it instead of the resistor. The result is that steady (or slowly varying) voltages appear mostly across the capacitor and quick changes appear mostly across the resistor.

Therefore, the voltage gain and phase delay are given as follows:

$$A_v = \frac{1}{\sqrt{1 + (f_0/f)^2}}$$

$$\phi = \text{ArcTan}\{f_0/f\}$$



(a) (b)

Fig. 9. (a) Low pass filter, (b) High pass filter

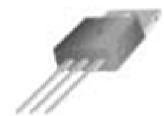


Fig. 10. Regulator

Capacitors are used as filters to remove ripples from the DC voltage and reduce the harmonics of the input voltage. There are two types of filters: Low pass filter and High pass filter. Regulators are used to regulating the output voltage to be always constant, and when the internal resistance of the supplies greater than 30 ohms, the output gets affected. The regulators are mainly class fixed for low voltage and high voltage, and can also be classified as a positive regulator. The most important data is in this text are that the input pin is the ground pin, the ground pin is the input pin, and the output pin is the negative regulator. The ground pin regulates the positive voltage, while the input pin regulates the negative voltage. The 78xx series ICs are used to generate fixed voltages of plus 3 V, plus or minus 5 V, 9 V, 12 V, or 15 V when the load is less than 7 amperes. The 7805 is a positive voltage DC regulator that has only 3 terminals. It employs internal current limiting, thermal shutdown, and safe area compensation, and can deliver output currents over 1.0 ampere. The 7812 12V integrated circuit s a monolithic integrated circuit TO220-type package designed for use, it can be us with external components to obtain adjustable voltages and currents.

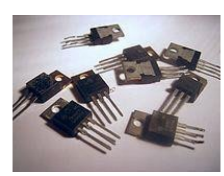


Fig. 11. Fixed regulator

2) Output filter:

The Filter circuit is often fixed after the Regulator circuit. Capacitor is most often used as filter. It charges during the positive half cycle of the AC voltage and discharges during the negative half cycle. So, it allows only AC voltage and does not allow the DC voltage. This filter is fixed after the Regulator circuit to filter any of the possibly found ripples in the output received finally. Here we used 0.1µF capacitor. The output at this stage is 5V and is given to the Microcontroller. The initial energy, Ei, is:

Ei = 1/2*(L*Ii^2 + C*Vi^2)

The final energy, Ef, is:Ef = 1/2*(L*If^2 = C*Vf^2)

The final voltage Vf is:

Vf = (Vi^2 + (Ii*Zo)^2)^1/2

Overshoot Voltage is the orthogonal vector sum of the output voltage and load current times the characteristic impedance. It is caused by a short circuit on the output and the overshoot is I*Zo, which can be very large, resulting in a ruinous overshoot.

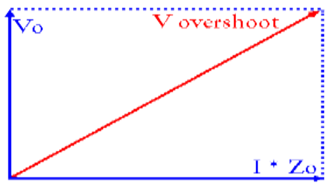


Fig. 12. Overshoot voltage as vector sum

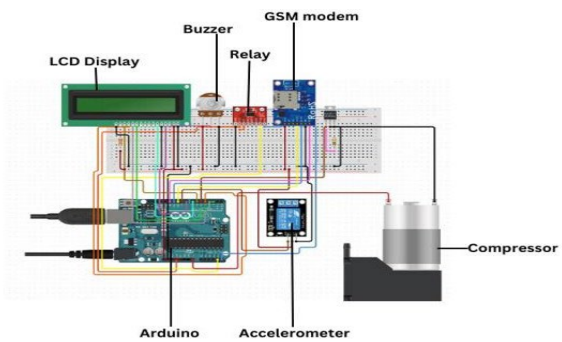


Fig. 13. Circuit diagram

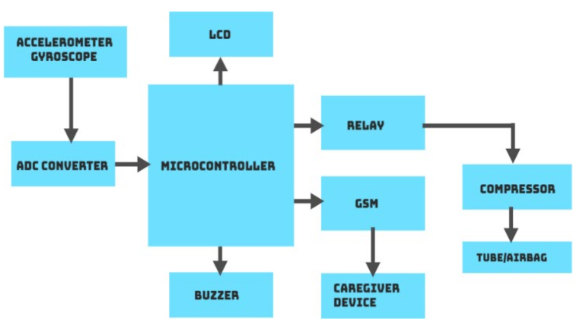


Fig. 14. Block diagram

The goal of this project was to develop and build an elderly fall detection system. The device needed to be wirelessly connected to a laptop, computer and wearable. The system needed to be able to recognize hazardous tilts as well as when a fall has taken place. The tool had to be able to alert the user and others in case of an accident or hazardous tilts. The device must first be able to sense motion and the various measurable qualities associated with motion in order to be able to identify fall.

E. Data Collecting Unit

The digital tri-axis accelerometer has the three coordinate axes are the first component of the device's sensing system. An analog bi-axial gyroscope records the angular speeds of the object's pitch and roll. The sensor data must be output to a microcontroller for processing and application to algorithms in order to use these sensors to identify falls [10]. In order for the microcontroller to use the sensor data, an analog voltage signal must first be converted to a desire sized bit value To achieve this, the sensor signals are first passed through an Analog Digital Converter (ADC) before being input into the microcontroller must use various elegant Ohms and conversion factors to process discretized but data from the ADC to determine the required variables (acceleration magnitude de, angle change, angular velocity) These variables are fed into an algorithm by the, which compares the inputs to various threshold values and starts triggers when certain thresholds are reached or surpassed [1].

F. Fall Detection Algorithm

The algorithm examines to see if the acceleration magnitude (AM) exceeds a lower threshold that has been established. The algorithm then checks to see if AM breaks a pre-determined higher threshold within 0.5s if the lower threshold Id is crossed. The algorithm then tests to see if the person's orientation has changed in a predetermined range within 0.5 seconds, which would suggest a person has fallen or toppled over if the upper threshold is violated. If the subject's station has changed, the algorithm then checks to see if it does so after 10 seconds. If it does, it means the subject is immobile in their prone posture on the ground. The algorithm recognizes this as a descent if this is accurate. Any intermediate decision circumstance that fails would cause the reset. The strength of this algorithm is that it needs an activity to break two AM thresholds and have an orientation change. Ideally, this extra lower threshold would decrease the number of false positives and send you back to the beginning.

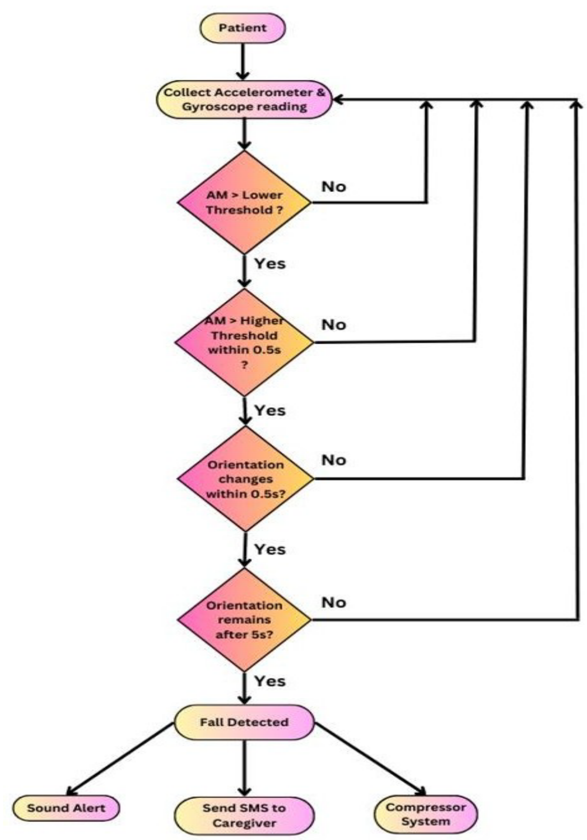


Fig. 15. Flow chart for fall detection algorithm

G. Data Transmission and Protection Unit

The GSM contacts the contact number provided in the code with the attenuation comm and once the fall has been confirmed. A buzzer sound and the message “Fall Detection Alert” are both sent to the guardian's contact and notify onlookers of the possibility of a fall This system also includes es an alarm that instantly inflates when a fall is detected to protect the users from fractures and other severe injuries.

4. Result

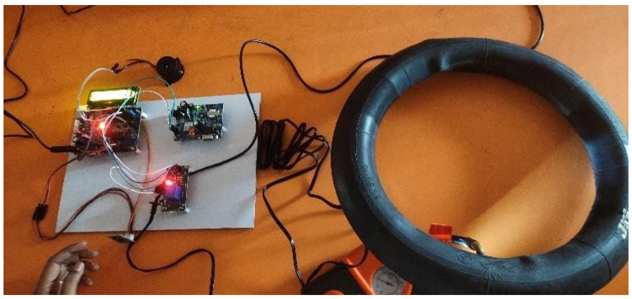


Fig. 16. Output of the device

5. Conclusion

In this study, we have used a wearable fall detection and protection device to track a subject’s fall in real-time and to share that information right away with a carer or guardian. This method is based on the data collected from sensors, and one of the main tasks that came out by this application is accurately detecting the event of a fall and activating an air bag for protection while also sending a warning SMS to the guardian.

Accuracy = TP+TNTP+FP+FN+TN

Sensitivity = TPTP+FN

Specificity = TNTN+FP

Description:

- TP = True Positive (human falls and sensor reports falling)
- TN = True Negative (human does not fall and sensor reports no fall)
- FP = False Positive (human does not fall but sensors detect fall)
- FN = False Negative (human fall but sensor reports no fall).

With the result from Table 2, the fall can be accurately calculated with an accuracy of 85%, sensitivity of 77%, and specificity of 100%. Thus, our fall detection algorithm works accurately in detecting the fall event.

Table 2

Category	Condition	Sensor	Ket
Falls backward	Ends in a sitting position	Falls	FN
	Ends in a lying position	Falls	TP
	Ends in a sideways position	Falls	TP
Falls forward	With knees	Falls	FN
	With arm protection forward	Falls	TP
	Ends in a prone position	Falls	TP
	Ends in a lying position	Falls	TP
	With rotation, ends in a sideways position to the right	Falls	TP
	With rotation, ends in a sideways position to the left	Falls	FN
Falls to the right side	Ends in a sideways position to the right	Falls	TP
	Ends in a lying position	Falls	TP
Falls to the left side	Ends in a sideways position	Falls	TP
	Ends in a lying position	Falls	TP
ADL	Sits on a chair then stands up	Doesn't fall	TN
	Lies on the mattress then get up	Don't fall	TN
	Walks a few meters		TN
	Bends then return to position upright	Not falling	TN
	Running	Not falling	TN
	Climbing stairs	Not falling	TN
	Go downstairs	Not fall	TN

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