applied sciences

MDPI

Article

Airbag Protection and Alerting System for Elderly People

Mariam Ibrahim [1,*], Shuruq Shawish [2], Sabri Aldroubi [1], Ali Dawoud [2] and Walid Abdin [2]

[1] Department of Mechatronics Engineering, German Jordanian University, Amman 11180, Jordan; s.aldroubi@gju.edu.jo

[2] Department of Mechanical and Maintenance Engineering, German Jordanian University, Amman 11180, Jordan; shorouq.shaweesh@gju.edu.jo (S.S.); a.dawoud@gju.edu.jo (A.D.); w.abdin@gju.edu.jo (W.A.)

* Correspondence: mariam.wajdi@gju.edu.jo

Abstract: In the elderly population, falling is an important cause of severe injuries like hip injuries. Injury- or unconsciousness-related immobility implies that the affected are unable to seek assistance. Building fall detection systems is essential since it is usual for senior individuals residing alone to go many hours without being located after a fall, considerably increasing the impact of injuries caused by falls. The primary goal of this paper is to implement an airbag protection and alerting system for elderly people. The system can be installed on a waist belt as an airbag. It is connected wirelessly to the elderly person's mobile, where an Android mobile application is created to receive alert notifications from the system. The system will detect the fall using a gravity sensor that is connected to an Arduino board. If a fall is detected by the gravity sensor, then the system will activate an air valve and inflate the airbag from the air tank. The system will also send a warning notification to the elderly person's mobile application via Bluetooth. Then, the elderly person's GPS location will be determined from their mobile phone and an SMS will be transmitted to a mobile phone belonging to his/her emergency contact of choice. The system is tuned to provide a proper fall detection sensitivity with good accuracy (90%). It has a relatively low cost, very quick response time (only 150 ms delay from the electrical grid), and low power consumption (11.1 Wh).

Keywords: fall detection; elderly; alerting; fall protection; global positioning system (GPS); good health and wellbeing

check for updates

Citation: Ibrahim, M.; Shawish, S.; Aldroubi, S.; Dawoud, A.; Abdin, W. Airbag Protection and Alerting System for Elderly People. *Appl. Sci.* **2023**, *13*, 9354. https://doi.org/10.3390/app13169354

Academic Editors: Wendong Xiao, Zhan Zhang, Jie Zhang and Yunlong Zhao

Received: 19 July 2023
Revised: 12 August 2023
Accepted: 15 August 2023
Published: 17 August 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The proportion and numbers of elderly people have recently increased and are expected to continue to rise in many nations, raising concerns about this potentially vulnerable age group's wellbeing. In developing nations, this demographic transition is occurring at a faster rate. In Jordan, the aged (those over 60) make up roughly 4.6% of the population, compared to a slightly higher 5.6% for the Arab world as a whole. It is anticipated that the percentage will rise to 6.8% in 2025 and 15.3% in 2050 in the Arab world. This increase can be attributed to several components, such as a decline in overall fertility rates, a decline in infant and child mortality rates, an increase in life expectancy, a decline in mortality rates, an improvement in health services, an increase in education levels, particularly among women, improved nutrition, and changes in living conditions [1].

Among the fractures that orthopedic trauma teams see most frequently are hip fractures. Hip fractures in the elderly place a burden on the world's health systems and are a significant public health concern in the majority of nations. According to some statistics, the frequency of hip fractures is anticipated to skyrocket during the following several decades. Planning healthcare strategies requires a thorough understanding of the epidemiology of hip fractures. The average life span of the world's population is rising, more individuals are living into their later years, and many of them are living solo compared to the past. As a result, diseases that appear later in life bear a greater weight on health.

Among the most significant consequences of becoming older is osteoporosis. Consequently, it is anticipated that more comorbid persons may experience osteoporotic hip fractures. By 2050, there will be 4.5 million more hip fractures worldwide than there were in 1990 (1.26 million) [2].

Falls can be a serious public health interest for the elderly population globally, as they can reduce mobility, independence, and superior of life if not prevented in time. Falls are a common cause of fatal wounds like hip fractures in older individuals, and if the affected person is incapable of seeking help due to injury or unconsciousness, it is not uncommon for them to go undiscovered for several hours. To address this, systems that detect falls are crucial to observe and prevent the harmful effects of falls. However, many current systems using individual sensors have limited effectiveness due to a high number of incorrect warnings and an inability to protect the elderly if there is a fall. The primary contribution of this work is to design an Arduino-based system that not only detects the falling of the elderly but also provides fall protection through the inflation of an airbag. Moreover, a novel Android mobile application is developed to receive alert notifications and send an SMS to the elderly person's relatives with their location using Android smartphone features. The system prototype is designed with SolidWorks. The airbag can be worn around the waist and it is connected via Bluetooth to an Android mobile device. The fall detection system uses a gravity sensor connected to an Arduino board to detect falls. If a fall is identified, the system activates an air valve to inflate the airbag from an air tank and sends a warning notification to the elderly person's mobile application. The system also uses the GPS on the elderly person's mobile device to determine his/her location and sends an SMS to the emergency contact of choice.

Related Work

For many years, there has been an extensive amount of interest in falls from both a research and business perspective. Several technological methods can be categorized based on the services they provide. These categories are fall detection, fall detection and protection, and tracking the location of the elderly. For instance, for the fall detection category, [3] created a wearable gadget that can wirelessly connect with a laptop or cell phone to dial emergency numbers when falling is detected. Additionally, it may recognize an unusual tilt and alert users to adjust their posture to reduce the danger of falling.

Four different static postures: standing, bending, sitting, and laying are identified by [4]. The TEMPO (technology-enabled medical precision observation) 3.0 sensor nodes have been used. The proposed method encounters difficulties in distinguishing between bed-jumping and wall-falling with a seated position.

A wearable accelerometric motion analysis system (WAMAS) is suggested by [5] for the evaluation and treatment of movement-related disorders. The core of the system is comprised of four 3-axis sensors: two upon the hips on a belt at the waist, and two more attached to the edges of the eyeglass to monitor head movements. However, a reduced weight unit still requires development.

A real-time fall detection and pose recognition system is being developed by [6] that may be utilized in the home. It uses a single camera placed on the ceiling for monitoring based on motion information. However, using a camera may not be a comfortable method as it breaches a person's privacy all the time.

An accelerometer with an ultrasonic sound sensor is utilized in a fall detection system proposed by [7]. While an accelerometer is utilized to identify motions, an ultrasonic sensor uses distance measurements to determine a person's free fall motion. When both sensors' thresholds are achieved, the system initiates a fall event and sends an emergency warning to the caregivers and the physicians through a GSM module.

A smart helmet for the blind is designed by [8]. It includes some functions like obstacle detection and fall detection. The helmet is equipped with a few sonar sensors that can detect objects across 360 degrees surrounding the wearer. The system keeps sending help requests throughout the fall incident using the GSM module until one of the pre-designated caretakers answers.

A fall alarm scheme is developed by [9] which comprises a linear array of electret condenser acoustic sensors installed on pre-amplifier boards Cana Kit CK495. A motion detector is included in the acoustic fall detection system (FADE) to further reduce false alerts.

A monitoring system is designed by [10] to detect falls and sudden changes in a person's mobility. The gadget may be installed on a person's hand or wheelchair to detect motion and uses an accelerometer and gyro sensor to do so. A quick shift that causes the system to jolt is handled as a fall.

A safety alarm device is proposed by [11] that may be worn as a pendant or a wristband which is connected to a regular phone and has an emergency button to send an alert to an alarm receiver or family. However, it can only be effective if the elderly person using the gadget is aware.

Philips Lifeline [12] offers fall detection devices using accelerometers and barometers. When a fall is detected by the sensors, an automated alert is sent to the Philips Lifeline response center through a base station installed in the home. However, the call cannot be canceled by the user if the help button is pressed accidentally.

For the fall detection and protection category, an Arduino-based human airbag system is implemented by [13] to safeguard the elderly from falls. The system has to be wearable and capable of detecting dangerous tilt and if a fall has occurred. It uses a 3-axis sensor accelerometer and gyroscope which are connected to a microcontroller which detects the fall and sends a command to the driver circuit to inflate an airbag.

A smart helmet system is suggested by [14] to detect unexpected falls for people who drive motorcycles or elderly people. A 3-axis accelerometer is used to observe the fall, then it transmits a signal to an Arduino which in turn operates an air compressor to pump air into the airbags.

A fall detection and prevention system that monitors the posture in bed is proposed by [15]. Whether the user is in bed or not is determined using pressure sensors. The prevention system consists of the IMU Puck.js to monitor the user movements and an ESP32 node which has the pressure sensors connected to three analog inputs. It can only be utilized if the user is lying on the bed.

A human airbag technique is used by [16] for hip protection. The system uses micro-electromechanical system (MEMS) motion sensors for detecting the elderly person's imbalance or falling. This system is supposed to have small airbags that will inflate when the MEMS motion detection unit detects their unbalance.

A jacket is developed by [17] that automatically inflates an airbag to cushion the impact of a fall and lessen the force on the wearer's head and hips when he/she falls. The system consists of a battery, a gas case, sensors to measure acceleration and angular velocity, a prompt device that releases the gas, and an inflator to pump out the gas which causes the airbag to automatically inflate.

For the location tracking category, a wearable-sensor-based fall detection system is proposed by [18]. The wearable equipment will identify the individual and promptly alert caretakers if a fall is determined. The device will return to fall detection mode and send an SMS message to the caretakers if the user disables the alarm.

An operational model was implemented by [19] for a fall monitoring wristband. A Raspberry Pi, an IMU chip, a GPS module, a 4G connection module, and a reset button make up the device. The model uses a cellular network to transmit information about major falls, including their location and environment's temperature, to a remote care center. It has high power consumption and its size is not convenient.

While the reviewed literature provides one or two of the three services, our proposed system can provide all of them. It provides a fall detection mechanism using a gravity sensor connected to an Arduino board to detect falls. It also protects the elderly person when a fall is detected using an air valve to inflate the airbag from an air tank. The system sends a warning notification to the elderly person's mobile application and uses the GPS on the elderly person's mobile device to determine his/her location. It also sends an SMS to the emergency contact of choice. The system has a relatively low cost (JOD 113.25), very quick response time (only 150 ms delay from the electrical grid), low power consumption (11.1 Wh), and very good accuracy (90%).

2. Methodology

Figure 1 displays the flowchart for how the system operates. It starts with Bluetooth initialization, and then the gravity sensor values of the acceleration on the x, y, and z-axes will be read by the Arduino Nano. The Arduino will decide if the measured values indicate a fall case according to a threshold value. We used the mean square root method to determine the threshold since it requires larger readings for such an application. The gravitational acceleration on the three axes is based on the sensor's specs and configuration, rather than using a single axis or the simple averaging method.

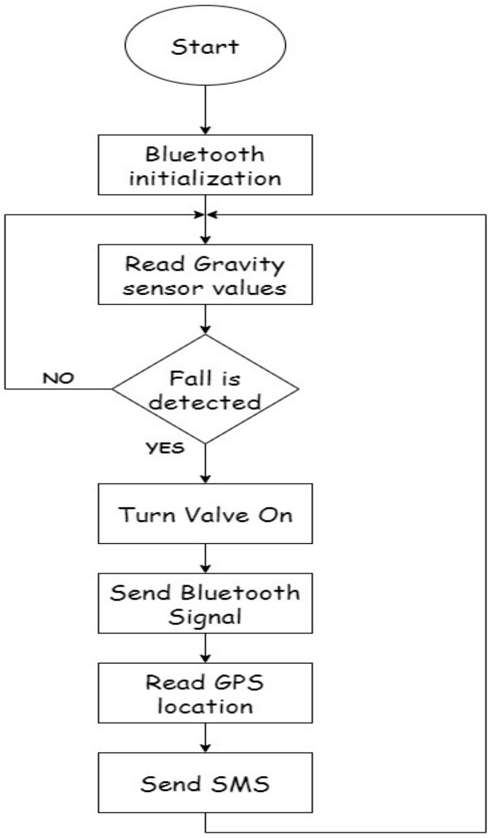


Figure 1. System working flowchart.

The root mean square was utilized to establish the threshold as follows:

$$\vec{a} = \sum_i \vec{a}_i = \begin{pmatrix} a_x \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ a_y \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ a_z \end{pmatrix} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \quad (1)$$

$$\left|\vec{a}\right| = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (2)$$

If a fall is not detected, it continues reading the gravity sensor values. If a fall is detected, then the Arduino turns the valve on and sends a Bluetooth signal to the mobile application connected to the system. After that, the user's location will be determined using the Android mobile's GPS and will be sent to the user's emergency contact number as an SMS.

Figure 2 illustrates the system block layout. The system works as follows:

1. The system is worn across the waist and is turned on.
2. The Bluetooth module is then connected to his/her mobile phone.
3. The system will detect a fall using a gravity sensor that is connected to an Arduino board.
4. When a fall is detected by the gravity sensor, the system will activate an air valve and inflate an airbag from an air tank.
5. The system also sends a warning notification to the elderly person's mobile application via Bluetooth.
6. Then, the GPS location will be determined from his/her mobile phone and an SMS will be transmitted to the mobile phone belonging to the person of the user's choice (his/her emergency contact).

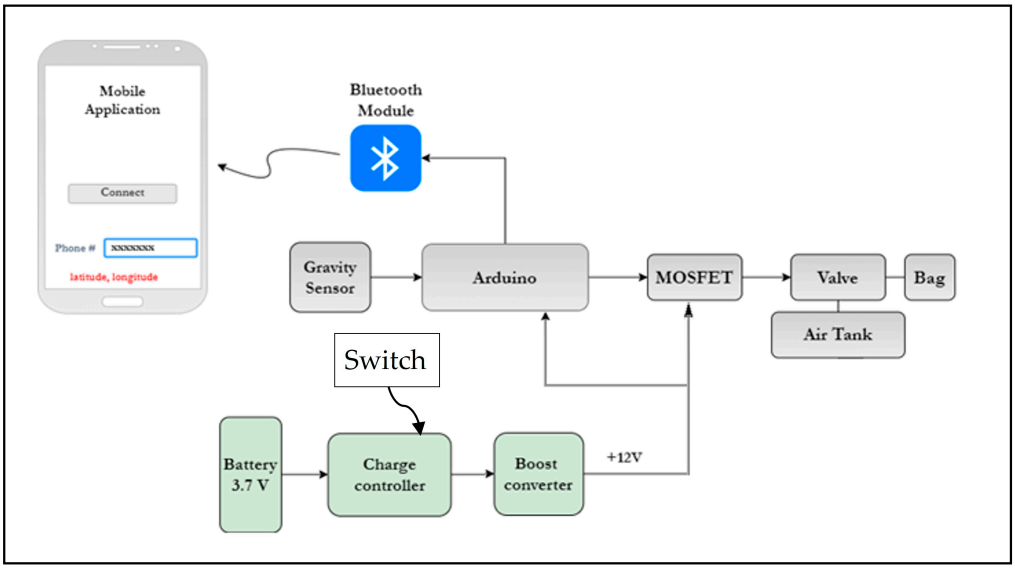


Figure 2. Proposed system block layout.

The charge controller is used to safeguard the battery from charging excessively and releasing limits; it switches off attached loads when the battery is low and turns them back on when the battery is charged again; in addition, it stops the flow of charge to the battery once the battery is full when attached to the charger. The switch is placed after the charge controller so that it can cut the power from the residual components of the system. The boost converter will step up the battery voltage from 3.7 v to 12 v to supply the Arduino and the valve (through the transistor), and the Arduino will supply the sensor (ADXL345) and the Bluetooth module (HC-06) with 5 volts. The system components are listed below:

- Arduino Nano: It has a built-in programmer and USB port on the board [20].
- Accelerometer (gravity sensor): This is a type of wearable sensor that is widely used in fall detection systems. An accelerometer sensor measures the acceleration of objects in their instantaneous rest position. It indicates the object's accelerations in three directions including the gravity effect [21]. It has low power consumption, and it suits devices that have outdoor applications. The chosen accelerometer is ADXL345; it is a 3-axis MEMS accelerometer which has a high resolution (13-bit) magnitude at up to $+/-16$ g, is compact, thin, and consumes low power [22].
- The solenoid in the air valve: It controls the valve's opening and closing. A solenoid is made up of a coil of wire that induces a magnetic field when current flows through it; the shaft inside the coil moves because of this magnetic field, the shaft moves up when the solenoid is activated, opening the valve. When the solenoid is turned off, the shaft descends once more, closing the valve. The solenoid can operate with 6 to 12 volts,

which is too high to be driven by the Arduino 5-volt supply, so the value receives its voltage from the boost converter. Then, a transistor is utilized to control the valve [23].

The flow rate of the air valve is calculated using the following formula:

$$Flow\ Rate\ (L/min) = SCFM \times 28.32 \tag{3}$$

$$Flow\ Rate\ (L/min) = 22 \times 28.32 = 623.04\ L/min$$

where $SCFM$ is the flow rate of gas under standard pressure and temperature conditions (standard cubic feet per minute).

- MOSFET (metal oxide semiconductor field-effect transistor): To supply the air valve, a driving transistor should be used. That is because the Arduino cannot provide the valve with enough power to operate. The chosen MOSFET is the IRF520 module. The transistor breakout board is contained in this little module (HCMODU0083). The module is made to switch large DC loads from a single microcontroller digital pin. To connect the load and an external power supply, screw terminals are provided [21].
- A Bluetooth BLE module: It establishes a protocol for data transmission between devices and serves as an interface for wireless Bluetooth low energy connections between any two devices. The average mediated data communication range of a Bluetooth low energy module is typically tens of meters, and data are transmitted in designated frequency bands. The chosen Bluetooth module is HC-06. It is a class-2 slave Bluetooth module designed to allow wireless serial communications between microcontrollers like Arduino and other Bluetooth-enabled devices [24].
- Battery: As the system is proposed to be wearable, a high capacity and lightweight rechargeable battery should be used. The lithium-ion battery was selected with a charge controller to protect it from overcharging and over discharging limits. The lithium battery charger TP4056 module can charge lithium-ion rechargeable batteries and offers the necessary protection needed by lithium-ion batteries in addition to safe charging. The module's input voltage is 5 V, and the maximum charging current is 1000 mA (1A) [25].

The battery used is 3.7 volt and its capacity is 3000 mAh. The power consumption is calculated as:

$$\begin{aligned} Battery\ Power\ Consumption\ (P) &= V \times I \\ &= 3.7 \times 3 = 11.1 \text{ Watt-h} \end{aligned} \tag{4}$$

The battery charging time to the maximum is given by:

$$Battery\ Charging\ time = \frac{Battery\ watt - hour}{Charger\ Power\ (watt)} \tag{5}$$

The charger used is 5 volt and 1 A, then:

$$\begin{aligned} &Charger\ power = V \times I \\ &\text{Charger power} = 5 \times 1 = 5 \text{ Watt} \\ &\text{System's battery charging time} = \tfrac{11.1}{5} = 2.22 \text{ h} \end{aligned} \tag{6}$$

- The boost converter MT3608 module was used to supply the Arduino Nano with the needed voltage and to operate the 12-volt DC valve directly. It is a cheap module that can step-up a 2 to 24 V input voltage up to a 5 to 28 V output at up to 2 A. Since the module cannot output more power than its inputs, DC-DC boost converters scale up the input voltage to a higher voltage while also ramping down the available current [26].
- Air tank: The two sides of the pipe were closed by a plastic gland using specialized glue made and sold for these pipes, a hole was made at one of its sides for the air inlet using

a stem (tire valve), and the pipe will be filled with air by an air compressor through the stem, and another hole was made for the air outlet by connecting a pneumatic fitting, which will be connected with the solenoid valve inlet using an 8 mm pneumatic pipe, while another fitting will be utilized to connect the valve outlet with the airbag via another 8 mm pneumatic pipe.

- Airbag: A bubble wrap sheet shaped as an airbag and sealed using durable duct tape, covered with a fabric case, that is closed around it using a zipper, and the cloth has three fabric slits used to attach it to the user's pants using the user's belt.

Figures 3–6 illustrate the detailed layout views of the scheme that was designed using SolidWorks.

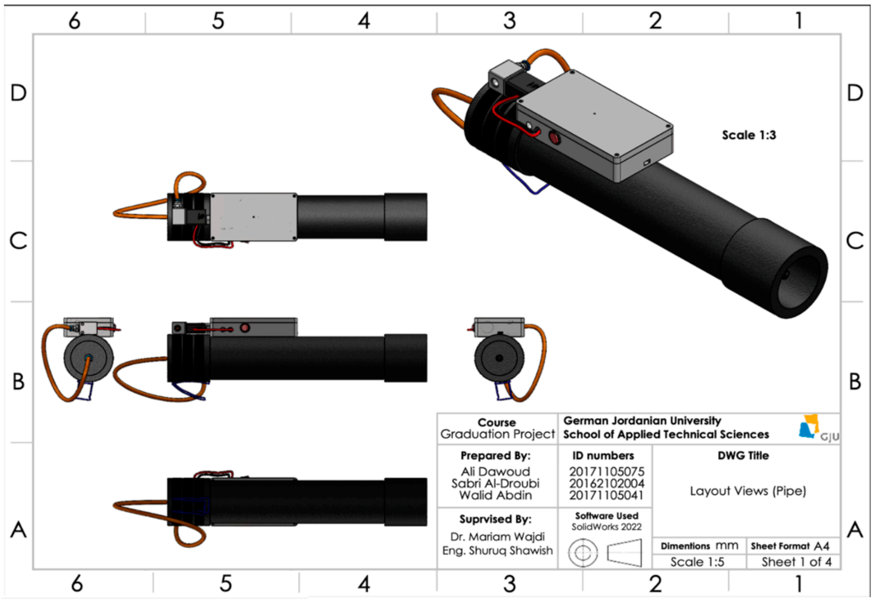


Figure 3. Pipe layout views.

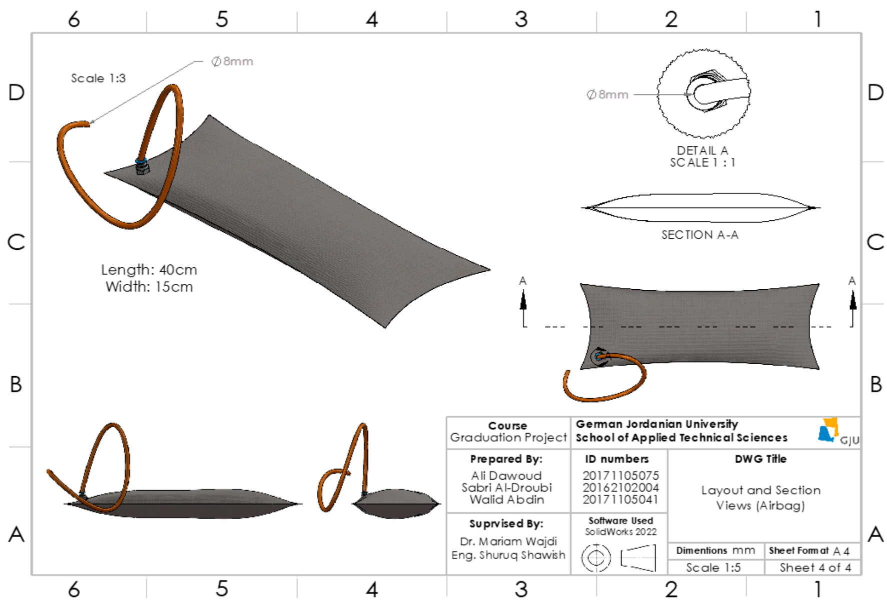


Figure 4. Airbag layout and section views.

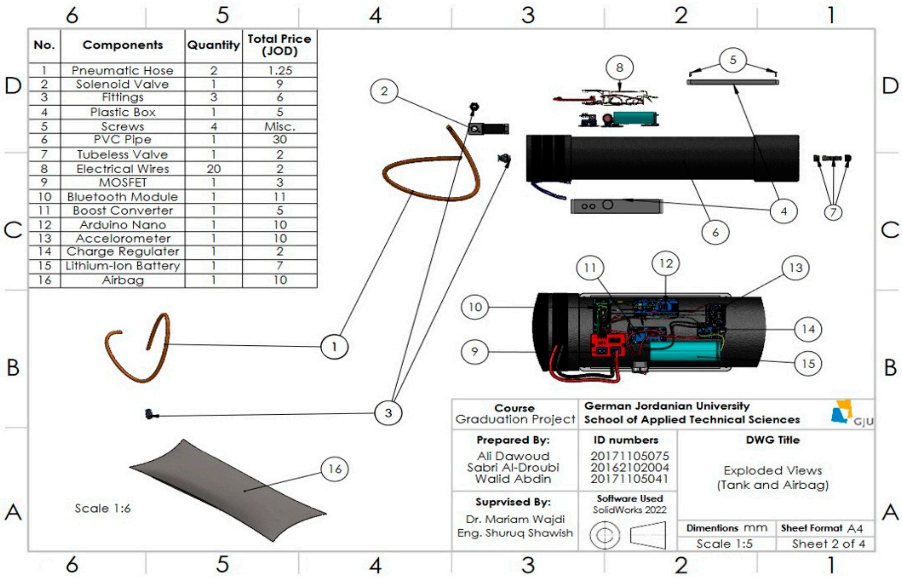


Figure 5. Exploded view and component prices in JOD.

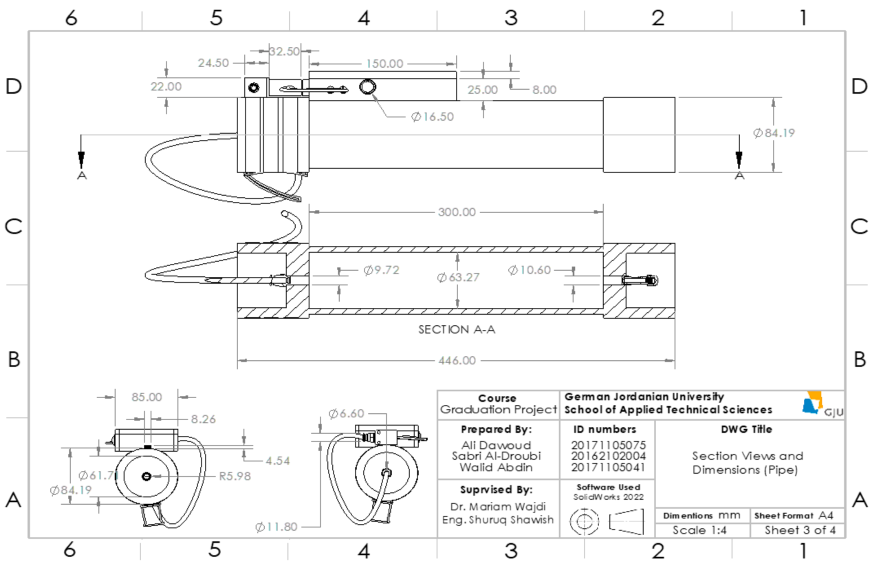


Figure 6. Pipe section views with dimensions.

3. System Implementation

3.1. Hardware Implementation

In this section, we illustrate the hardware implementation and circuits used. Starting with the power supply circuit implementation that is presented in Figure 7, the lithium-ion battery is connected with the module's pins (B+, B−), while the module's output pins (out+, out−) are connected with the boost converter input pins (VIN+ and VIN−). The switch is used to turn the system on and off. The boost converter output is adjusted to 12 V to power the system.

The Arduino connections are provided in Figure 8. The ADXL345 accelerometer module is linked to the Arduino utilizing the I2C protocol. The module's Vcc pin is linked to 5 volts from the Arduino pin +5 V, the GND pin with the ground, SDA pin with the Arduino's A4 pin, and the SCL pin with the Arduino's A5 pin. The HC-06 Bluetooth module Vcc pin is linked to the Arduino's +5 V pin and its GND pin is linked to the earth to operate. This module communicates with the Arduino via the UART protocol, which occurs by connecting its TX and RX pins to the Arduino Nano D2 and D3 pins, respectively.

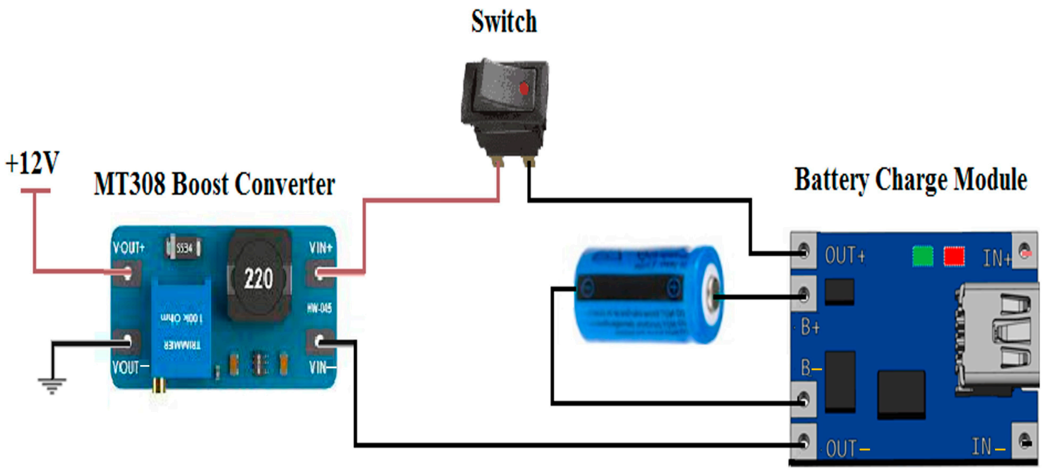


Figure 7. Power supply circuit connections.

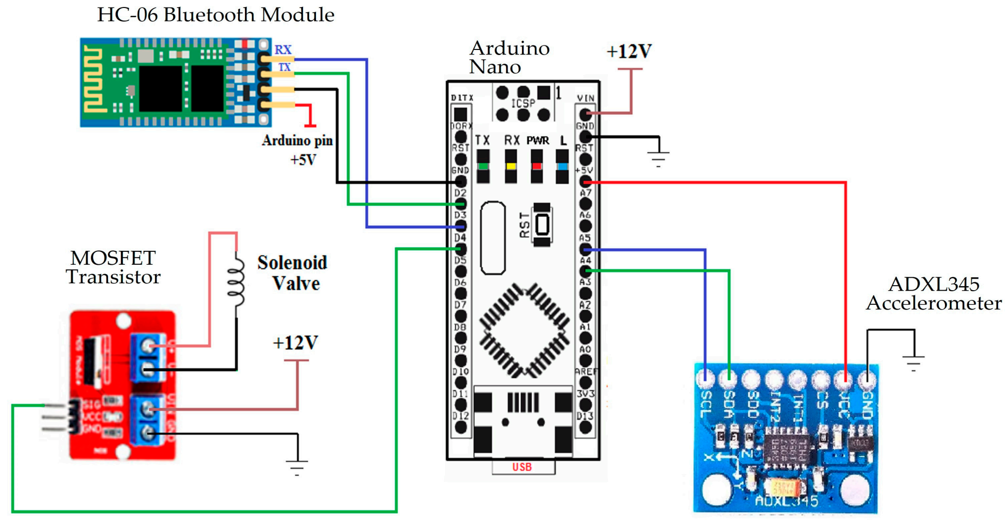


Figure 8. Arduino connections.

The solenoid valve is driven by the IRF520 MOSFET, because the Arduino cannot provide the valve with enough power to operate. The IRF520 MOSFET Vin and GND pins are linked to +12 V (from the boost converter) and ground, while the solenoid valve is linked to the MOSFET module's output pins V+ and V−. Finally, the signal pin of the MOSFET module is linked to the Arduino D4 pin to receive the signal to drive the valve.

The real design wirings are demonstrated in Figure 9. The power supply circuit, Arduino Nano, HC-06, ADXL345, and the MOSFET module are installed inside a plastic box. It also shows how the solenoid valve is connected with the MOSFET module.

Figure 10 shows the outer scheme of the box and how it is attached to the air tank body.

Figure 11 demonstrates the final scheme of the airbag. It has been designed using a plastic bubble case that is covered by fabric and connected with the valve's outlet to fill it with air when the valve is activated. Holders have been placed so it can be easily worn on the back of the waist by weaving it through the belt.

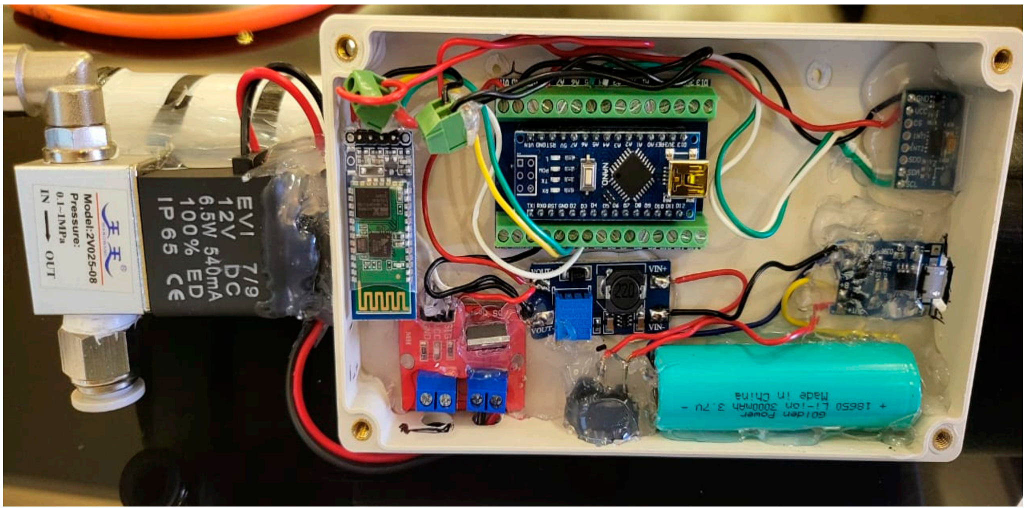


Figure 9. Real design connections.

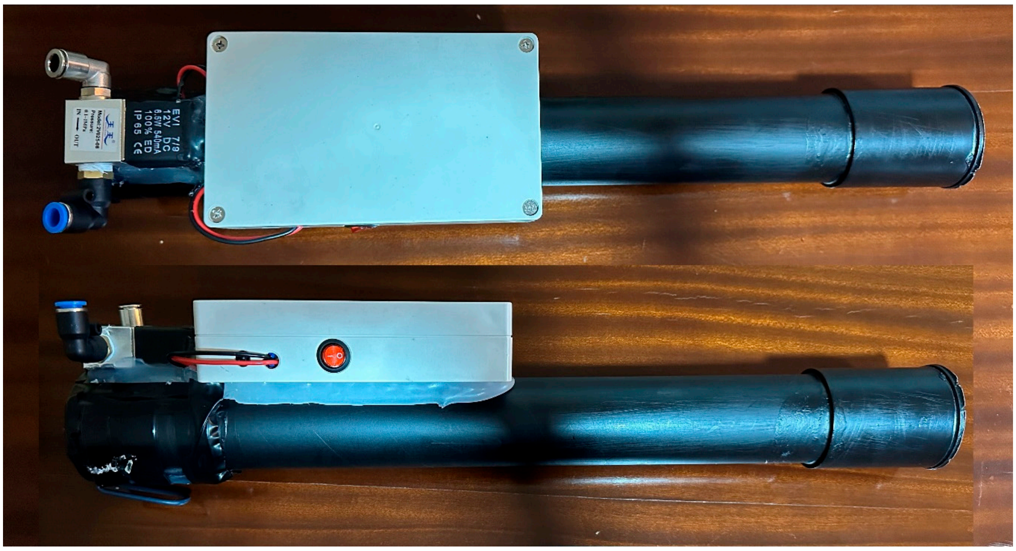


Figure 10. System outer design.

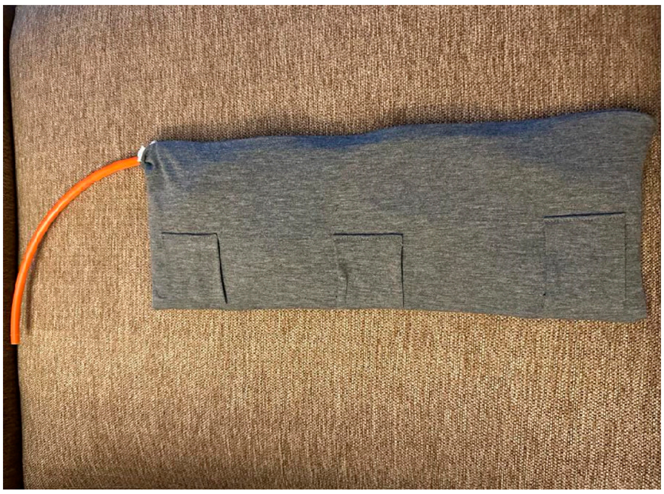


Figure 11. Airbag.

3.2. Software Implementation

The Arduino IDE 1.8.5 software for programming the Arduino Nano board was used in this project [27]. By using the Arduino IDE software, we devised a code for the system to recognize when a person falls. The Arduino is familiar with all the electrical components in our system except for the ADXL345 accelerometer, so we added a library called "Adafruit" that helps the Arduino connect with the ADXL345 accelerometer. The required libraries were called at the start of the code, where pin number D4 has been declared as the output of the Arduino to the transistor to open the solenoid air valve.

Pin D2 and D3 on the Arduino for the TX and RX pins on the Bluetooth module, respectively, and four float variables have been declared "at, xa, ya, and za" which are, total acceleration, acceleration on the x-axis, acceleration on the y-axis, and acceleration on the z-axis, respectively. These are the initial steps to the code.

In the setup section of the code [void setup()], the HC-06 Bluetooth module and the ADXL345 accelerometer were initialized by setting the baud rate to 9600 for the Bluetooth module and setting the ADXL345 accelerometer sensitivity to 16 G (from either 2 G, 4 G, 8 G, 16 G) which sets the sensitivity to the acceleration of the ADXL345 accelerometer. Pin D4 on the Arduino was set to zero to ensure that the valve does not get a signal until a fall occurs.

In the loop section of the code [void loop()], "xa, ya, and za" were set to the acceleration of the x-axis, y-axis, and z-axis, respectively. The total acceleration "at" is set to the mean square root of "xa, ya, and za". Considering the value of "at", an "if statement" is written to determine if the person fell or not as follows: if the total acceleration is larger than the threshold, a string will be transmitted to the Bluetooth module to tell the mobile application that a fall has occurred, a signal will be sent to pin D4, and a signal will reach the MOSFET transistor that will send 12 volts to the solenoid valve to open and inflate the airbag.

For developing the Android application, a graphical user interface, MIT App Inventor was used. It is an open-source online application for Android; it was first made available by Google and is currently maintained by the Massachusetts Institute of Technology (MIT). Everyone can create fully working apps for smartphones and tablets using the MIT App Inventor, which is a user-friendly, visual programming environment.

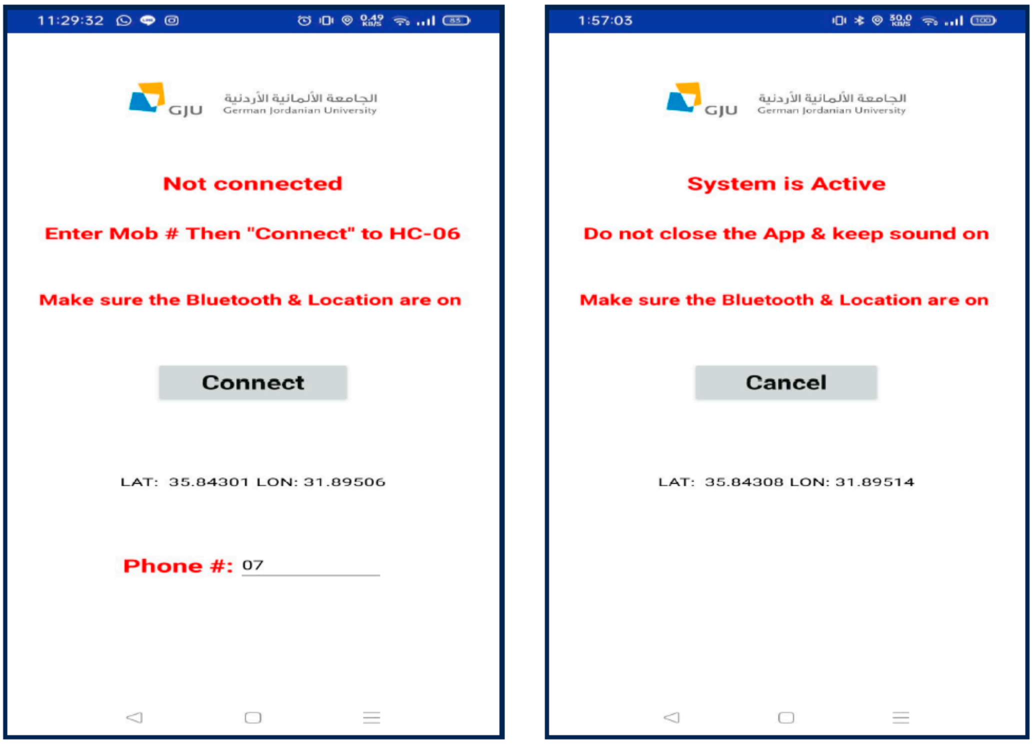
The developed mobile application interface before connecting to the Bluetooth module is shown in Figure 12. It shows the mobile application connection status with the hardware via Bluetooth and some instruction messages for both before and after connecting the device. It also shows the field where the mobile number of the user's emergency contact should be entered.

When the Arduino sends a signal to the mobile application (via the HC-06 Bluetooth module), the location of the user (latitude and longitude) will be determined using the mobile's built-in GPS and shown on the mobile application interface.

After a mobile number is entered and the phone is linked to the Bluetooth module, the mobile application interface changes and shows the status of "System is Active" as given in Figure 12b, thus, saving energy.

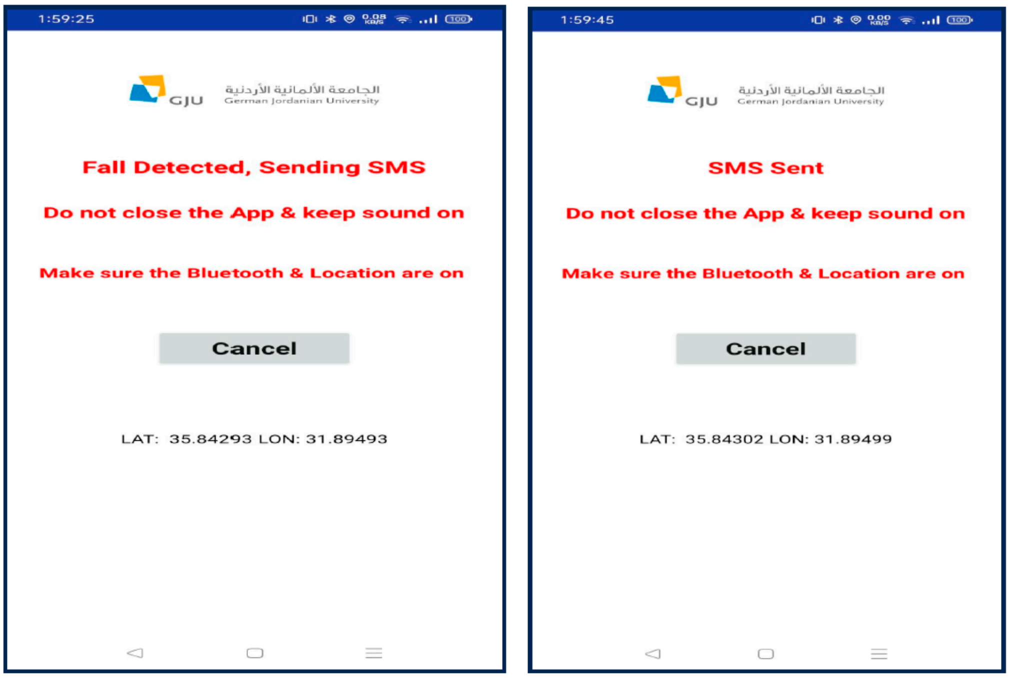
The system is ready to receive a signal from the Bluetooth module when a fall is detected. When this occurs, the Arduino transmits a signal to the Bluetooth module which is next transmitted to the mobile application. Figure 13a shows the mobile application interface when the fall is detected. After fifteen seconds (the cancellation period) with the SMS sent, the interface is shown in Figure 13b.

If a fall occurs, the person has the option to cancel the SMS from being sent if they do not require attention. The cancelation period is fifteen seconds; if the person chooses to cancel the SMS from being sent in that time frame, the interface of the mobile application is presented in Figure 14.



(**a**) (**b**)

Figure 12. (**a**) Interface before connection; (**b**) Interface after connection.



(**a**) (**b**)

Figure 13. (**a**) Fall detected, sending SMS interface; (**b**) SMS sent interface.

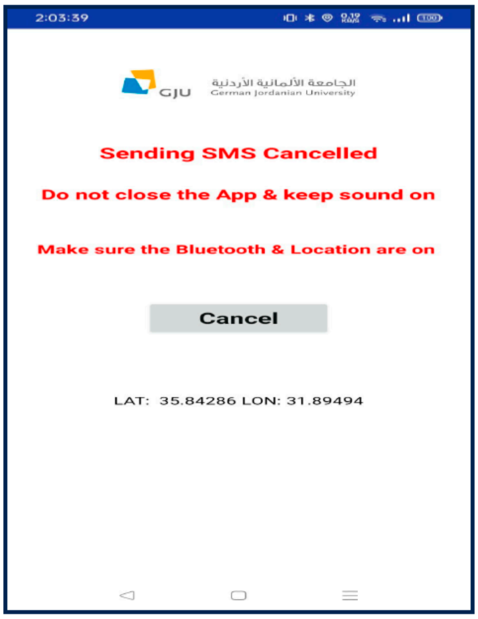


Figure 14. Sending SMS canceled interface.

Finally, after the fall has occurred, the SMS message is sent to the emergency contact of the elderly/disabled person that contains a text that says "Fall detected at location" along with a Google Maps link that shows the location of the fall. The SMS message is illustrated in Figure 15.

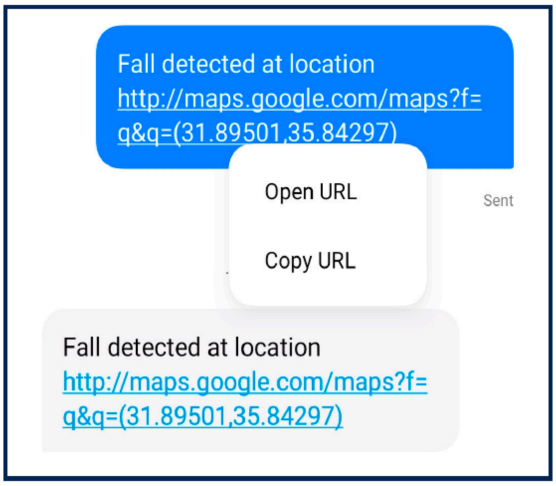


Figure 15. Received SMS content.

4. Results and Discussion

This part represents the experimental findings and engages in a comprehensive discussion of their implications. Figure 16 shows the final design of the proposed system. All experiments were conducted related to the standing position. Environmental conditions were all assumed to be within the specifications and ambient conditions provided in the sensor's datasheet. Also, the pipe was made of plastic, so it was resistant to corrosion. The electrical components were covered with silicon and placed in a plastic box. This makes the system relatively water and dust proof. The electrical components have a relatively high resistance to heat based on their data sheets and our tests.

Figure 16. Final system design.

When designing the system, we calibrated our ADXL345 accelerometer to read on a sensitivity of 16 G (which corresponds to the acceleration unit of gravity). The ADXL345 accelerometer can read through a sensitivity of 2 G, 4 G, 8 G, and 16 G (the higher the number the higher the sensitivity to motion, the lower the number the higher the accuracy of the acceleration readings).

All results were measured by experiments and trials, so some trials already included some faults (false falls). The testing process was as follows, we simulated 10 free-fall tests for different G's and thresholds. The system would open at the right time, too late, too early, or not open at all. Considering all the cases as failures except for when it opened at the right desired time (not too late, too early, or not at all), the number of right times divided by 10 (total number of falls) represents the accuracy of the system at the certain configuration of G and threshold.

For a threshold of 10 and 15, the system would be too sensitive to motion, and it would result in the airbag inflating when no fall had occurred (by normal movements). For a threshold of 30, the system would be unresponsive and would result in a fall without the airbag inflating (most of the time it only responded to very sudden actions, and it would open after the fall had occurred). For a threshold of 25, the system would mostly be unresponsive for the lower G's but was 70% accurate on 16 G. For a threshold of 20, the results were better than a threshold of 25 but the airbag would sometimes inflate on sudden movements such as sudden changes in direction and fast complete stops. After testing thresholds between 20 and 25, we found an optimum threshold of 22 for the ADXL345 accelerometer sensitivity of 16 G.

The 2 G only reads within a range of ± 2 gravitational units (g). This means it can accurately measure accelerations from -2 g to +2 g. This range is suitable for applications that involve relatively low accelerations, which is not suitable for the system's application. The 4 G and 8 G only read within a range of ± 4 and ± 8 gravitational units (g), respectively, which means they can accurately measure accelerations from -4 g to +4 g and -8 to +8, respectively. These ranges are useful for applications where moderate accelerations need to be measured. The 16 G is a suitable range for our system because it is sensitive to high changes in acceleration with an accuracy of readings that is suitable for providing the right results for our application (hitting the threshold or not). Through testing, it yielded the best results. The accuracy through various G's and thresholds is shown in Figure 17.

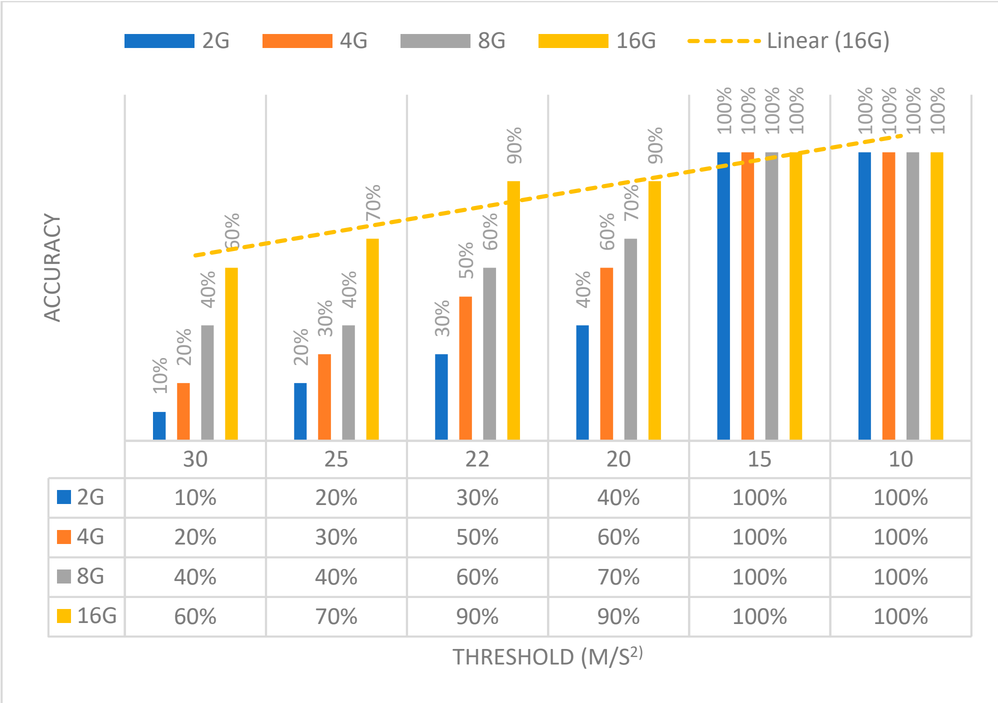


Figure 17. Accelerometer's accuracy under various thresholds.

Comparing our design to others in the literature, our system can provide waist fall protection as opposed to [3–12,18,19] which do not provide any protection against falls. Our system is also capable of sending notification alerts when a fall occurs via SMS including the location information, whereas this feature is not provided by [3–17]. The proposed system has a relatively low cost (JOD 113.25), very quick response time (only 150 ms delay from electrical grid), low power consumption (11.1 Wh), and very good accuracy (90%). Thus, increasing the applicability of our system.

All of our components are function-safety critical. They were selected to achieve a long operating life with the smallest size, lightest weight, highest quality, greatest reliability, and with a minimum cost, thus increasing system efficiency. Components were purchased from trusted manufacturers who use proven manufacturing methods. Duplicating electrical components to achieve redundancy will not be cost effective nor provide a suitable size.

The average life span (useful life) of the system consists of three phases, where each phase is critical to a certain kind of component:

- Phase I (wear in, infant): This phase is critical for software programs as most failures in this phase occur due to design flaws or wrong assembly, for example: Arduino Nano microcontroller.
- Phase II (useful life): This is the longest phase and the most predictable, as most errors or failures are random. Electronics experience this phase the most, for example: Boost converter.
- Phase III (wear out): This phase occurs due to stress, fatigue, and aging which applies to most well assembled and designed mechanical components, for example: Solenoid air valve.

Table 1 illustrates our system's average life span criticality on a scale from 0–3, where 0 is least critical to 3 which is most critical.

Table 1. Average life span criticality.

Components	Average Criticality Life Span
Microcontroller	1
Sensor	1
Valve	1
Valve driving transistor	1
Wireless technology	0
Power supply	3
Charge regulator	1
Boost converter	1
Plastic pipe	0
Pneumatic pipe	2
Fittings	2
Fabricated airbag	0

A maintenance plan suitable to the nature of this system's components and needs is displayed in Table 2.

Table 2. Maintenance plan.

Component	Life Span	Maintenance Type	Justification
Arduino Nano	Around 2–3 years (hot environment), up to 10–15 years (cool environment)	Scheduled maintenance (let a technician test it, if it functions store it for emergencies, if not salvage) Change the part every 5 years	Checkups are not possible, we must take a short yet suitable period both financially and practically because our system is a safety system, so we need to have a safety factor or margin
Gravity sensor (ADXL345)	∞	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is no specified expiry or life span
Solenoid air valve	Approximately 5 million cycles	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is almost no need for maintenance since it can run so many times while our application does not logically require even a close number of cycles, but we still do it for extra safety
MOSFET IRF520	∞	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is no specified expiry or life span
Bluetooth BLE module (HC-06)	∞	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is no specified expiry or life span
Lithium-ion battery 3.7 v, 3A (charge)	A minimum of 8 h	Scheduled maintenance (check every 8 h for battery percentage and recharge regularly)	
Lithium-ion battery 3.7 v, 3A (life span)	Around 2–3 years or 300–500 charge cycles	Scheduled maintenance (change just before the 2-year mark)	Checkups are difficult, so we must take a short yet suitable period both financially and practically because our system is a safety system, so we need to have a safety factor or margin

Table 2. *Cont.*

Component	Life Span	Maintenance Type	Justification
Charge regulator	∞	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is no specified expiry or life span
Boost converter (MT3608)	∞	Condition-based maintenance (let a technician test it, if it functions reuse it, if not salvage)	There is no specified expiry or life span
30 in, 50 cm plastic pipe	∞	Condition-based maintenance (check for the fitment, leaks, and degradation by eye every now and then)	It is supposed to last for a lifetime (under normal operating conditions, it did not activate many times), but you can never be too safe
Pneumatic pipe	∞	Condition-based maintenance (check for the fitment, leaks, and degradation by eye every now and then)	It is supposed to last for a lifetime (under normal operating conditions, it did not activate multiple times), but you can never be too safe
Fittings	∞	Condition-based maintenance (check for the fitment, leaks, and degradation by eye every now and then)	It is supposed to last for a lifetime (under normal operating conditions, it did not activate many times), but you can never be too safe
Fabricated airbag	∞ (unless it is punctured after a fall)	Condition-based maintenance (check for leaks or punctures after inflation)	Since when a fall does not occur on the bag, degradation will not happen

5. Conclusions

Sustaining good health and wellbeing among the elderly is essential. Falls among the elderly are a global public health concern, which causes diminishing mobility, independence, and quality of life. Hip fractures are a common result of these incidents, which cause increasing immobility and risk, especially as the elderly/disabled may be unable to seek help. In this work, an airbag system was developed using Arduino and an Android app for fall detection, protection, and alerting. A wearable detection system activates an airbag when a fall is detected, while a signal is simultaneously transmitted to the mobile application, and a GPS location and warning are transmitted to the emergency contact as an SMS. In the future, further enhancements can be incorporated in the system implantation to be a smaller, wearable size for enhanced comfort. This can be achieved by making the pipe smaller, changing the hose length, and hoisting locations such as on a walker, as the size turned out to be more than enough to fully inflate the airbag. Applying artificial intelligence (AI) techniques is another future direction including obstacle detection and avoidance, as well as detecting false falls, thus reducing false alarms and increasing detection rate and accuracy.

Author Contributions: Conceptualization, M.I. and S.S.; methodology, M.I. and S.S.; software, S.A., A.D. and W.A; validation, M.I. and S.S.; formal analysis, M.I. and S.S.; investigation, S.A., A.D. and W.A.; resources, S.A., A.D. and W.A.; data curation S.A., A.D. and W.A.; writing—original draft preparation, M.I., S.S., S.A., A.D. and W.A.; writing—review and editing, M.I. and S.S.; visualization, M.I. and S.S.; supervision, M.I. and S.S.; project administration, M.I. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sawsan, M. Survey of the Health of the Elderly in Jordan. *Med. J. Islam. Acad. Sci.* **2000**, *13*, 39–48.
2. Dawod, M.S.; Alisi, M.S.; Saber, Y.O.; Abdel-Hay, Q.A.; Al-Aktam, B.M.; Alfaouri, Y.; Alfraihat, L.B.; Albadaineh, A.A.; Abuqudiri, A.Z.; Odeh, R.M.; et al. Characteristics of Elderly Hip Fracture Patients in Jordan: A Multicenter Epidemiological Study. *Int. J. Gen. Med.* **2022**, *2022*, 6591–6598. [CrossRef] [PubMed]
3. Tomkun, J.; Nguyen, B. Design of a Fall Detection and Prevention System for the Elderly. Bachelor's Thesis, McMaster University Hamilton, Hamilton, ON, Canada, 23 April 2010.
4. Li, Q.; Stankovic, J.A.; Hanson, M.A.; Barth, A.T.; Lach, J.; Zhou, G. Accurate, fast fall detection using gyroscopes and accelerometer-derived posture information. In Proceedings of the 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks, Berkeley, CA, USA, 3–5 June 2009; pp. 138–143.
5. Sabelman, E.E.; Schwandt, D.; Jaffe, D.L. The wamas (wearable accelerometric motion analysis system: Combining technology development and research in human mobility. In Proceedings of the ConfERENCE Intellectual Property in the VA: Changes, Challenges and Collaborations, Arlington, VA, USA, 12–13 April 2001.
6. Aertssen, J.; Rudinac, M.; Jonker, P.P. Real time fall detection and pose recognition in home environments. In Proceedings of the International Conference on Computer Vision Theory and Applications, Vilamoura, Portugal, 5–7 March 2011; Volume 2, pp. 409–414.
7. Manigandan, S.; Norman, S.R. Fall detection system for elderly person monitoring using GSM network. *Int. J. Adv. Eng.* **2015**, *1*, 78–83.
8. Jaiswal, V.; Singh, N.; Mishra, S.; Singh, G. Blind person smart helmet. *Int. J. Res. Pap. Publ.* **2022**, *10*, 3857–3861. [CrossRef]
9. Popescu, M.; Li, Y.; Skubic, M.; Rantz, M. An acoustic fall detector system that uses sound height information to reduce the false alarm rate. In Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Vancouver, BC, Canada, 20–25 August 2008; pp. 4628–4631.
10. IoT Based Person/Wheelchair Fall Detection Project. Available online: https://nevonprojects.com/iot-based-personwheelchair-fall-detection/ (accessed on 10 July 2023).
11. Hardani, S.; Venkatesh, T. Automatic Fall Detection, Alert and Assessment to Improve Pre-hospital Emergency Care Response. Master's Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2020.
12. Automatic Fall Detection. Available online: https://www.lifeline.com/medical-alert-systems/fall-detection/ (accessed on 10 July 2023).
13. Hita, P.; Ashika, N.A.; Shilpa, N. Arduino Based Human Airbag System for Fall Protection for the Elderly. *Int. J. Curr. Eng. Sci. Res.* **2018**, *5*, 2394–8374.
14. Prakash, N.; Kumar, U.; Vashan, S.S.G.; Sudhakaran, M. Smart Helmet for Fall. *Int. J. Sci. Res. Sci. Eng. Technol.* **2018**, *4*, 380–384.
15. Fernández-Bermejo Ruiz, J.; Dorado Chaparro, J.; Santofimia Romero, M.J.; Villanueva Molina, F.J.; del Toro García, X.; Bolaños Peño, C.; Llumiguano Solano, H.; Colantonio, S.; Flórez-Revuelta, F.; López, J.C. Bedtime monitoring for fall detection and prevention in older adults. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7139. [CrossRef] [PubMed]
16. Chan, C.S.; Shi, G.; Luo, Y.; Zhang, G.; Li, W.J.; Leong, P.H.; Leung, K.S. A human-airbag system for hip protection using MEMS motion sensors: Experimental feasibility results. In Proceedings of the International Conference on Mechatronics and Automation, Luoyang, China, 25–28 June 2006.
17. Tamura, T.; Yoshimura, T.; Sekine, M.; Uchida, M.; Tanaka, O. A wearable airbag to prevent fall injuries. *IEEE Trans. Inf. Technol. Biomed.* **2009**, *13*, 910–914. [CrossRef] [PubMed]
18. Wu, F.; Zhao, H.; Zhao, Y.; Zhong, H. Development of a wearable-sensor-based fall detection system. *Int. J. Telemed. Appl.* **2015**, *2015*, 2. [CrossRef] [PubMed]
19. Hammarstedt, O. Fall Detection Bracelet with an Accelerometer and Cellular Connectivity. Master Thesis, Uppsala University, Kista, Stockholm, 2019.
20. Arduino Nano Board: Features, Pinout, Differences and Its Applications. Available online: https://www.elprocus.com/an-overview-of-arduino-nano-board/ (accessed on 10 July 2023).
21. Murty, S.S.R. An Overview of Accelerometer Sensors. In *Handbook of Smart Sensors and Applications*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2020; pp. 1–24.
22. Triple Axis Accelerometer Module (ADXL 345). Available online: https://store.fut-electronics.com/products/triple-axis-accelerometer-module-adxl-345 (accessed on 10 July 2023).
23. Channel Relay Module and Air Valve. Available online: https://projecthub.arduino.cc/ejshea/1-channel-relay-module-and-air-valve-fbcf17 (accessed on 10 July 2023).
24. HC-06 Pinout, Specifications, Datasheet, and Arduino Connection. Available online: https://www.etechnophiles.com/hc06-pinout-specifications-datasheet/ (accessed on 10 July 2023).
25. Micro USB 1A Lithium Battery Charger Module. Available online: https://mikroelectron.com/Product/Micro-USB-1A-Lithium-Battery-Charger-Module/ (accessed on 10 July 2023).

26. MT3608 Step-Up Adjustable DC-DC Switching Boost Converter. Available online: https://www.addicore.com/MT3608-Boost-Converter-p/ad300.htm (accessed on 10 July 2023).
27. Arduino vs PIC Microcontroller: Everything You Need to Know. Available online: https://www.electroniclinic.com/arduino-vs-pic-microcontroller-everything-you-need-to-know/ (accessed on 10 July 2023).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.