Design and build an airbag system for elderly fall protection using the MPU6050 sensor module

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ABSTRACT

The use of technology has a significant impact to reduce the consequences of accidents. Sensors, small components that detect interactions experienced by various components, play a crucial role in this regard. This study focuses on how the MPU6050 sensor module can be used to detect the movement of people who are falling, defined as the inability of the lower body, including the hips and feet, to support the body effectively. An airbag system is proposed to reduce the impact of a fall. The data processing method in this study involves the use of a threshold value to identify falling motion. The results of the study have identified a threshold value for falling motion, including an acceleration relative (AR) value of less than or equal to 0.38 g, an angle slope of more than or equal to 40 degrees, and an angular velocity of more than or equal to 30 °/s. The airbag system is designed to inflate faster than the time of impact, with a gas flow rate of 0.04876 m^3/s and an inflating time of 0.05 s. The overall system has a specificity value of 100%, a sensitivity of 85%, and an accuracy of 94%.

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1. INTRODUCTION

The development of technology in the field of electronics has numerous benefits for daily life, including making work easier, providing comfort, and reducing the risk of work accidents [1], [2]. One area where technology can be particularly useful is in the realm of fall detection and prevention, particularly for elderly individuals who may be more prone to falls due to the decline in function of certain organs [3], [4]. Previous research has focused on the development of fall detection systems, which can alert family members or caregivers when a fall has occurred [5]. However, these systems do not address the issue of protecting the individual after a fall has occurred [6].

This study aims to address this issue by proposing the use of airbags as a protective measure for elderly individuals who have fallen [7]. The system works by using an MPU6050 sensor to detect falling motion, and activating an automatic solenoid valve to inflate the airbags before the individual hits the ground [8]–[10]. The use of airbags to mitigate the impact of falls has a long history, with the first prototypes being developed in the 1950s for use in vehicles [11]. Today, airbags are commonly used in supplemental restraint systems (SRS) in vehicles to protect the head, neck, and chest in the event of a collision [12]. The expansion of airbags is typically achieved through the use of a pressurized gas cylinder or a CO_2 cartridge, and the process takes approximately 1/25 of a second. In this study, a pressurized gas cylinder is used as the developer of the airbags [13].

2. METHOD

The development of airbag systems has been crucial in improving vehicle safety and reducing the risk of serious injuries in the event of a crash. In recent years, there has been a growing interest in designing airbag systems that not only protect the occupants but also minimize the impact on their bodies. In this context, the airbag system depicted in Figure 1, which takes the form of a belt and incorporates a fall detection module, is an innovative approach to improving occupant safety. The fall detection module utilizes a microcontroller and an MPU6050 sensor to detect changes in acceleration and angular velocity, enabling the airbag to deploy at the appropriate time, and with the appropriate force. In this article, we will discuss the design and development of this airbag system and its potential benefits for vehicle safety.

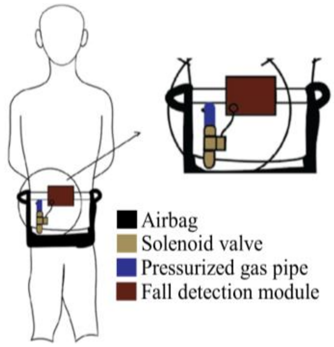

Figure 1. The airbag system design

In this research, there will be 11 movements that will be examined, namely walking, jogging, bowing, sitting, walking up the stairs, walking down the stairs, and prostrating, which will be referred to as regular movements. Additionally, falling backward, forward, to the left, and to the right, will be referred to as falling movements. To differentiate these 11 movements, the study utilized a threshold method based on acceleration, angle, and angular acceleration [14]. This method involves analyzing the total acceleration, total orientation values of normal motion or activity of daily living (ADL) and determining the maximum value as the threshold [15], [16]. A formula is used to calculate the acceleration relative (AR) to gravity because the orientation of falling motion is always downward, regardless of whether the fall is forward, backward, or to the side. The formula for calculating AR [17], is shown in (1).

$$AR = ((-1) * (Ax * sin(\alpha)) + (Ay * cos(\alpha) * sin(ß)) + (Az * cos(\alpha) * cos(ß))) \quad (1)$$

With the description of the value of α and the value of ß, α is the value of the pitch and ß is the value of the roll that is read by the sensor [18]. The values of sin and cos are included because the falling motion involves movement at an angle. The angle resulting from the falling motion will be calculated using the acceleration values read by the sensor. AR is a variable for the relative acceleration value [19], [20]. After obtaining the formula for relative acceleration, the next step is to determine the change in angle during the falling motion. This requires a trigonometric formula, shown in (2).

$$Angle = arccos(cos(\alpha)) * cos(\beta) \quad (2)$$

The (2) is necessary because when a person falls, the angle formed is not only based on pitch or roll but a combination of both [21]. The angle formed is not 90º, but rather slightly tilted from a right angle depending on the falling motion. In addition to the angle, the angular velocity of the sensor is also considered [22], [23]. The angular velocity formula is similar to the angular change formula, but using the pitch and roll gyro values in (3).

$$Angular\ Velocity\ = (Arccos(cos(\omega\alpha) * (cos(\omega\beta)) \quad (3)$$

The acceleration graph during a fall decreases and then rises again after impact once the person has fallen. The threshold graph can be seen in Figure 2. The main assumption in the fall detector is the use of free fall. As long as the acceleration signal falls, it is considered a free fall, meaning the acceleration is 0 [24]. Therefore, the acceleration prevention value is assumed to be below ±3 m/s^2. In addition, previous studies have shown that adding an angular velocity of less than 0.52 rad/s can also indicate a fall. Thus, a fall is detected when the acceleration is less than ±3 m/s^2 and the angular velocity exceeds 0.52 rad/s [25], [26].

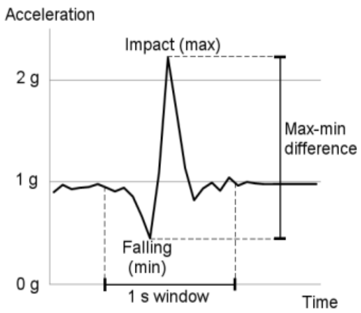

Figure 2. Acceleration graph when falling

3. RESULTS AND DISCUSSION

It can be observed from the comparison of the range between ordinary motion and falling motion, using the average value of AR acceleration, the minimum and maximum value of angle, and the minimum and maximum value of angular velocity, that a threshold value can be obtained to identify between falling motion and ordinary motion. Based on the reference, falling motion is categorized when the AR acceleration value is less than 3 m/s^2 or 1/3 g and the angular velocity exceeds 30 °/s. However, by using the threshold value based on the reference, the threshold value cannot be used directly because some ordinary movements still meet the threshold value. Therefore, tuning is required to obtain a threshold value that only meets the conditions of falling motion. The tuning was carried out on 40 trials of falling motion and 60 trials of ordinary motion, by changing the AR threshold value and the angle from the dynamic experimental data results. The AR threshold value was changed in increments of 0.02 and the angle was changed in increments of 10°. As a result of the tuning, the obtained threshold value for falling motion is an AR value of less than or equal to 0.38 g, an angled slope of more than or equal to 40°, and an angular velocity of more than or equal to 30 °/s. This threshold value is only fulfilled in falling movements and not in ordinary movements. After obtaining the threshold value, it will be entered into the Arduino program to detect falling motion.

Table 1 shows the duration of time between the initial detection of a fall and the occurrence of a collision using the obtained threshold value. The threshold value obtained for detecting falling motion does not apply to ordinary movements because the AR, angle, and angular velocity values in ordinary motion do not meet the threshold value conditions. Table 1 provides data on the duration of time between the initial detection of a fall and the occurrence of a collision using the threshold values obtained from the study. The results reveal that the threshold value for detecting falling motion does not apply to regular movements, as indicated by the lack of detection for walking, jogging, bowing, sitting, walking up and down the stairs, and prostrating. In contrast, falling movements, including falling backward, left, right, and forward, were successfully detected using the threshold method as their AR, angle, and if the angular velocity values do not meet the threshold value conditions, it means that the not detected activity is a good thing.

The data also demonstrate variations in the duration of time between the initial detection of a fall and the occurrence of a collision across different iterations, with some falls being detected more quickly than others. The negative numbers indicate that the system was able to detect the falling motion after the occurrence of the collision, rendering the airbag unable to protect the impact due to the delay in detection. Conversely, the positive numbers indicate that the system was able to detect the falling motion before the collision, allowing the airbag to fully deploy within the designated time window. Therefore, a larger positive number would indicate a better detection system, providing sufficient time for the airbag to fully deploy within the designated time window.

Out of 40 attempts of falling motion, 34 times the system successfully detected falls earlier than the time of impact. On the other hand, 6 times the system detected falling motion with a duration slower than the time of impact. The time difference between the detected time and the impact time for each repetition of the falling motion ranged from 0.01 to 0.08 s. The success or failure of the sensor to detect falls faster than the time of impact is influenced by the threshold value used to detect falling motion. In this study, the threshold value is only used to meet the conditions of falling motion, so an appropriate threshold value is needed to meet all falling movements and minimize failure between the initial detection and the fall. The average duration from the time of detection until impact was 0.05 s. This average value will be included in the results of the airbag module design.

The results of the design of the airbag showed the speed of time needed to inflate the airbag, the time (t) was calculated using the average duration between the initial detection of a fall and the time of impact, which was found to be 0.05 s for an airbag volume of 0.002438 m^3. After the design process, the airbag module was tested. The test results on the airbag module showed that the airbag had a gas storage pipe tube with a volume of 452 cm^3 and a pressure of 164,690 Pa. The gas could flow with a discharge rate of 0.04876 m/s^2 for a duration of 0.05 s. After designing the overall system, the performance of the tool was evaluated using three metrics: specificity, sensitivity, and accuracy. Specificity measures the ability of the tool to correctly identify ordinary movements, with the experiment being repeated 10 times for each type of normal movement. The percentage of specificity is 100%.

After conducting the experiment on ordinary movements, the percentage of specificity analysis was found to be 100% from 60 trials. The next step is to analyze the sensitivity and accuracy of the system in detecting falling movements. In the falling motion experiment, 10 trials were conducted for each type of falling motion. The number of trials was based on references from previous research on fall detection. The sensitivity of the system in detecting falling motion is quite high, with a percentage of 85%. This indicates that the system is able to detect falling motion successfully in most cases. However, it is important to note that there may still be some cases where the system fails to detect falling motion, potentially leading to a delay in activating the airbag module. On the other hand, the accuracy of the system is also relatively high, with a percentage of 94%. This means that out of all the trials conducted, the system was able to accurately identify falling motion in the majority of cases. However, it is important to consider that even with a high accuracy rate, there may still be some instances where the system incorrectly identifies a falling motion or fails to detect it together. Overall, the results of the fall detection system show that it is effective in identifying falling motion and activating the airbag module in a timely manner. However, it is important to continue improving and fine-tuning the system to increase its sensitivity and accuracy even further. This can potentially help to reduce the risk of injury in case of a fall and improve the overall safety of the system.

Table 1. Duration between detected falling motion and impact

Iteration	Walk	Jog	Bow	Sit	Upstair	Downstair	Prostrate	Fall			
								Backward (s)	Left (s)	Right (s)	Forward (s)
1st	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.03	0.06	-0.02	0.03
2nd	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.02	0.06	0.07	0.04
3rd	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.03	0.07	0.08	0.05
4th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.04	-0.05	0.07	0.06
5th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.03	-0.02	0.08	-0.03
6th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	-0.03	0.03	0.09	0.04
7th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.02	-0.03	0.08	0.06
8th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.05	0.03	0.08	0.05
9th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.04	0.06	0.07	0.03
10th	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	0.01	0.05	0.08	0.04

4. CONCLUSION

The results of this research show that the MPU6050 sensor can be used to identify falling motion by detecting and meeting the threshold value. The threshold value obtained to detect falling motion is an AR value of less than or equal to 0.38 g, an angled slope of more than or equal to 40°, and an angular velocity of more than or equal to 30 °/s. In the design of the airbag, a discharge of 0.04876 m/s^2 with a duration of 0.05 s was obtained. The overall system analysis of the tool showed a specificity of 100%, sensitivity of 85%, and accuracy of 94%.

REFERENCES

[1] H. Ramirez, S. A. Velastin, I. Meza, E. Fabregas, D. Makris, and G. Farias, "Fall detection and activity recognition using human skeleton features," *IEEE Access*, vol. 9, pp. 33532–33542, 2021, doi: 10.1109/ACCESS.2021.3061626.

[2] L. Martínez-Villaseñor, H. Ponce, and R. A. Espinosa-Loera, "Multimodal database for human activity recognition and fall detection," in *UCAmI 2018*, Oct. 2018, doi: 10.3390/proceedings2191237.

[3] M. I. Nari, S. S. Suprapto, I. H. Kusumah, and W. Adiprawita, "A simple design of wearable device for fall detection with accelerometer and gyroscope," in *2016 International Symposium on Electronics and Smart Devices (ISESD)*, Bandung, Indonesia: IEEE, Nov. 2016, pp. 88–91, doi: 10.1109/ISESD.2016.7886698.

[4] V. Mudeng, I. M. Hakim, S. S. Suprapto, and S. Choe, "An alternative athlete monitoring system using cost-effective inertial sensing instrumentation," *Journal of Electrical Engineering & Technology*, vol. 17, pp. 3581–3592, Sep. 2022, doi: 10.1007/s42835-022-01258-1.

[5] I. M. Hakim, V. Mudeng, and S. S. Suprapto, "Sport monitoring using inertial sensing for frequency and velocity examination," in *2020 10th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, Malang, Indonesia: IEEE, Aug. 2020, pp. 151–154, doi: 10.1109/EECCIS49483.2020.9263445.

[6] S. S. Suprapto *et al.*, "Gym training muscle fatigue monitoring using EMG myoware and arduino with envelope and sliding window methods," *International Journal of Reconfigurable and Embedded Systems (IJRES)*, vol. 12, no. 3, pp. 345-350, Nov. 2023, doi: 10.11591/ijres.v12.i3.pp345-350.

[7] D. Berardini *et al.*, "Fall detection for elderly-people monitoring using learned features and recurrent neural networks," *Experimental Results*, vol. 1, pp. 1–9, Jan. 2020, doi: 10.1017/exp.2020.3.

[8] H. Jian, "Design of angle detection system based on MPU6050," in *Proceedings of the 7th International Conference on Education, Management, Information and Computer Science (ICEMC 2017)*, Shenyang, China: Atlantis Press, 2017, doi: 10.2991/icemc-17.2017.2.

[9] G. Rescio, A. Leone, and P. Siciliano, "Supervised machine learning scheme for electromyography-based pre-fall detection system," *Expert Systems with Applications*, vol. 100, pp. 95–105, Jun. 2018, doi: 10.1016/j.eswa.2018.01.047.

[10] K. Fukaya, "Fall detection sensor for fall protection airbag," in *Proceedings of the 41st SICE Annual Conference. SICE 2002*, Osaka, Japan: Soc. Instrument & Control Eng. (SICE), 2002, pp. 419–420, doi: 10.1109/SICE.2002.1195434.

[11] Y. Lee *et al.*, "Experimental verification of fall simulation and wearable protect airbag," in *Proceedings of the 4th International Conference on Information and Communication Technologies for Ageing Well and e-Health*, Funchal, Madeira, Portugal: SCITEPRESS - Science and Technology Publications, 2018, pp. 215–218, doi: 10.5220/0006785202150218.

[12] S. Ahn *et al.*, "Optimization of a pre-impact fall detection algorithm and development of hip protection airbag system," *Sensors and Materials*, vol. 30, no. 8, pp. 1743-1752, Aug. 2018, doi: 10.18494/SAM.2018.1876.

[13] C. Qu, W. Zhang, and T. Niu, "Design of a wearable airbag system to prevent fall injuries for older adults," *Gerontechnology*, vol. 17(s), 2018, doi: 10.4017/gt.2018.17.s.189.00.

[14] T. Gimpel, S. Kiertscher, A. Lindemann, B. Schnor, and P. Vogel, "Evaluation of threshold-based fall detection on android smartphones," in *Proceedings of the International Conference on Health Informatics*, Lisbon, Portugal: SCITEPRESS - Science and and Technology Publications, 2015, pp. 598–604, doi: 10.5220/0005280805980604.

[15] S. Fudickar, A. Lindemann, and B. Schnor, "Threshold-based fall detection on smart phones," in *Proceedings of the International Conference on Health Informatics*, ESEO, Angers, Loire Valley, France: SCITEPRESS - Science and and Technology Publications, 2014, pp. 303–309, doi: 10.5220/0004795803030309.

[16] D. Razum, G. Seketa, J. Vugrin, and I. Lackovic, "Optimal threshold selection for threshold-based fall detection algorithms with multiple features," in *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, Opatija: IEEE, May 2018, pp. 1513–1516, doi: 10.23919/MIPRO.2018.8400272.

[17] K. Clarke, T. Ariyarathna, and S. Kumari, "Concept-to-implementation of new threshold-based fall detection sensor," in *TENCON 2021 - 2021 IEEE Region 10 Conference (TENCON)*, Auckland, New Zealand: IEEE, Dec. 2021, pp. 597–602, doi: 10.1109/TENCON54134.2021.9707236.

[18] T. de Quadros, A. E. Lazzaretti, and F. K. Schneider, "A movement decomposition and machine learning-based fall detection system using wrist wearable device," *IEEE Sensors J.*, vol. 18, no. 12, pp. 5082–5089, Jun. 2018, doi: 10.1109/JSEN.2018.2829815.

[19] A. Mao, X. Ma, Y. He, and J. Luo, "Highly portable, sensor-based system for human fall monitoring," *Sensors*, vol. 17, no. 9, Sep. 2017, doi: 10.3390/s17092096.

[20] F.-T. Wang, H.-L. Chan, M.-H. Hsu, C.-K. Lin, P.-K. Chao, and Y.-J. Chang, "Threshold-based fall detection using a hybrid of tri-axial accelerometer and gyroscope," *Physiol. Meas.*, vol. 39, no. 10, p. 105002, Oct. 2018, doi: 10.1088/1361-6579/aae0eb.

[21] E. Casilari, M. Álvarez-Marco, and F. García-Lagos, "A study of the use of gyroscope measurements in wearable fall detection systems," *Symmetry*, vol. 12, no. 4, pp. 1-22, Apr. 2020, doi: 10.3390/sym12040649.

[22] M. S. Astriani, Y. Heryadi, G. P. Kusuma, and E. Abdurachman, "Human fall detection using accelerometer and gyroscope sensors in unconstrained smartphone positions," *IJRTE*, vol. 8, no. 3, pp. 69–75, Sep. 2019, doi: 10.35940/ijrte.C3877.098319.

[23] T. Rungnapakan, T. Chintakovid, and P. Wuttidittachotti, "Fall detection using accelerometer, gyroscope & impact force calculation on android smartphones," in *Proceedings of the 4th International Conference on Human-Computer Interaction and User Experience in Indonesia, CHIuXiD '18*, Yogyakarta Indonesia: ACM, Mar. 2018, pp. 49–53, doi: 10.1145/3205946.3205953.

[24] O. Aziz, M. Musngi, E. J. Park, G. Mori, and S. N. Robinovitch, "A comparison of accuracy of fall detection algorithms (threshold-based vs. machine learning) using waist-mounted tri-axial accelerometer signals from a comprehensive set of falls and non-fall trials," *Medical & Biological Engineering & Computing*, vol. 55, no. 1, pp. 45–55, Jan. 2017, doi: 10.1007/s11517-016-1504-y.

[25] J.-S. Lee and H.-H. Tseng, "Development of an enhanced threshold-based fall detection system using smartphones with built-in accelerometers," *IEEE Sensors Journal*, vol. 19, no. 18, pp. 8293–8302, Sep. 2019, doi: 10.1109/JSEN.2019.2918690.

[26] N. Otanasap and P. Boonbrahm, "Pre-impact fall detection approach using dynamic threshold based and center of gravity in multiple Kinect viewpoints," in *2017 14th International Joint Conference on Computer Science and Software Engineering (JCSSE)*, NakhonSiThammarat, Thailand: IEEE, Jul. 2017, pp. 1–6, doi: 10.1109/JCSSE.2017.8025955.

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