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Cyclist Fall Detection System via the Internet of Things (IoT)

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Abstract: Cycling has recently become one of the most popular activities among people worldwide. It is a practical and pollution-free way of transportation. However, it has several risks and potential impairments for users. One of the causes of an individual's death or major injuries in an accident is a lack of first aid provision due to the emergency services that is not promptly receiving information about the event. The emergency response speed is critical for any accident. Therefore, this study developed a prototype of a cyclist fall detection system to produce immediate alerts regarding any fall incident and an accurate real-time location to the emergency contacts via smartphones. The proposed system used an ESP8266 as a microcontroller to collect and process the data from the sensors. An accelerometer sensor is also used to obtain the acceleration value to calculate the roll angle in determining the cyclist's and bicycle's orientation. A Global Positioning System (GPS) is installed in the proposed system to obtain the cyclist's real-time location. The fall detection system is connected with software named BLYNK to send an emergency alert to the selected contact. As a result, the developed prototype successfully detected a fall and sent an emergency alert to specific users. Along with that, the GPS also managed to produce an accurate reading of fall's real-time location.

Keywords: Cyclist, Fall Detection System, Sensors, Internet of Things

1. INTRODUCTION

Cycling has recently become one of the most popular activities among people worldwide. It is a practical and pollution-free way of transportation. People have used bicycles for exercise as a fitness regime, and scientists have proven that riding is one of the most acceptable ways to get in shape [1]. Transportation has evolved into an essential activity requiring not just adequate resources but also human decisions. Alternative modes of transportation have changed people's perceptions about cycling and have become compelling reasons to ride a bike [2].

However, over 900 bikers were murdered in the United States in 2013, according to the Centres for Disease Control and Prevention, and approximately 500 000 emergency visits were due to bicycle-related injuries. Cycling can strengthen muscular groups that can be utilized to maintain balance and strength, autonomy, enjoyment, and enhance cardiovascular function, however, cyclists have been known to suffer from cycling-related ailments. Due to their lack of awareness of their surroundings, cyclists are at risk of colliding with motor vehicles [3]. The primary cause of an individual's death or major injuries in an accident is a lack of first aid provision, which occurs due to emergency services not receiving information about the event promptly. The emergency response speed is critical for any type of accident. According to an analysis, if emergency response time is reduced by just one minute, the odds of preserving a person's life will increase by six percent [4].

To reduce response time, introducing the Internet of Things (IoT) would be one of the answers. IoT is a technology that allows the transmission between sensors and electronic devices via the internet [5]. Internet-of-thing (IoT) successfully applied in various fields, such as healthcare [6], agrotourism [7] and automotive [8]. Moreover, there is also a study on bicycle rental systems using IoT that has been done by Puyol et al [9]. They utilized Low-Power Wide-Area Network (LPWAN) to receive position, speed, and road safety data. Nadkarni et. al. [10] implemented IoT to transform a conventional bicycle into a smart version. They create a user-friendly interface to monitor the traveled distance, burnt calories, and real time location of their smart bicycle.

Therefore, the IoT has the potential to assist in reducing response time and, as a result, deaths. It is necessary to create a system based on the IoT theory that can detect

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a fall and issue an emergency alarm in real-time to reduce reaction time. A A Global Positioning System (GPS) would also reduce the response time by sending the location of the cyclist. The rescue team can know the exact location of the cyclist and provide emergency rescue in a short time. Thus, this study proposes a cyclist fall detection system using IoT to enhance emergency response time.

2. LITERATURE REVIEW

A. Fall Detection Sistem

Harari et al. [11] have created a system that uses a smartphone as a platform to identify when someone is about to fall. The accelerometer and gyroscope on the smartphone were used to track the movement of the participants. A regularized logistic regression is used to detect the occurrence of a fall. Those fall-related characteristics will be sent to a web portal built for data exploration. These variables will include the event time, weather, the chance of falling, the participant's losing position, and activities before the fall.

Wang et al. [12] have proposed a wearable sensor for each individual. Falls frequently cause physiological changes in the human body, which can be used as a criterion for detecting a fall. They recommended employing accelerometers, gyroscopes, glucometers, pressure sensors, electrocardiography (ECG) [13], [14], electroencephalography (EEG), and electromyography (EMG) [15] to detect irregularities within things. Wearable devices have been extensively explored as valuable fall detection sensors due to their advantages of mobility, portability, availability, and low cost. Several studies have looked into the practicality of wearable devices, which is a potential direction for fall detection and prediction.

Li et al. [16] noted that because humans engage in some fall-like activities, such as hurriedly sitting down and springing, utilizing merely accelerometers would lead to many false positives. However, it is not very helpful when the body ending posture is not horizontal, such as falls on stairs. They have suggested a revolutionary fall detection system incorporating an accelerometer and gyroscope. Their technique, which uses accelerometers and gyroscopes, will significantly improve detection accuracy by decreasing false positives and false negatives.

According to Hwang et al. [17], the research has stated that their system uses the accelerometer, tilt sensor and gyroscope. They are using Bluetooth for real-time monitoring. The accelerometer will measure kinetic force. On the other hand, the tilt sensor, and gyroscope estimate body posture. They have suggested attaching the fall detection system, which contains the sensor, to the chest. They have a 96.7% accuracy on their fall detection system.

Zhang et al. [18] have suggested that the Home Healthcare Sentinel System might be utilized to identify falls in housebound older persons. This study employs a three-step detection strategy with a range of signal sources, including an accelerometer sensor, audio, pictures, and video clips via speech recognition and on-demand video algorithms. Speech recognition and on-demand video are combined to detect falls by the accelerometer, which also determines the magnitude value corresponding to the user's movement. The fall detection system will be activated in the event of a fall, and an urgent alarm email will be sent to medical personnel or caretakers. The email will include details on the fall; caregivers can use this information to establish a preliminary diagnosis.

According to Flores et al. [19], a fall detection system for cyclists will detect a fall and activate the combination with the GPS to give the coordinates of longitude and latitude. The application will automatically send an SMS to the cyclist's contacts selected in the app and the exact location where the cyclist has fallen. This system has implemented services for fall detection, emergency alert, and location. Accelerometer, GPS, contact selection, and SMS services have been used. They have used the accelerometer available in the smartphone in fall detection service. They have chosen SMS technology as it guarantees to be compatible with any cell phone available.

An indoor IoT fall detection system for older people has been proposed by Yacchirema et al. [20]. Smart devices, low-power wireless sensor networks, cloud computing, and big data are benefits of this fall detection system. A wearable device that is in charge of real-time data collection from older adults' movements includes a 3D-axis accelerometer integrated into it. To increase productivity, the sensor data is processed and analyzed using a Big Data model based on decision trees operating in a smart IoT gateway. When a fall is detected, the warning will go out, and the system will send alerts to the team in charge of caring for the elderly.

B. Using Accelerometer to Obtain Tilt Angle

Tuck [21] have stated that an accelerometer can use for tilt sensing. Tilt is a static measurement. In order to determine the orientation of an object, the force of gravity has been used as an input to calculate the degree of tilt. The accelerometer will experience acceleration between -1g to +1g through 180 degrees of tilt which 1g is equal to $-9.8m/s^2$. One of the examples of using an accelerometer is the joystick for a game controller. Accelerometers are used to detect the joystick's tilt motions. This action can let users feel more immersed in the game. Kimberly has proposed some formula to define the angle of the accelerometer in three dimensions which are roll, pitch and, theta, using all three outputs from the accelerometer. The angle of the y-axis relative to the ground is defined as Roll (ϕ), the angle of the x-axis relative to the ground is defined as Pitch(ρ), and the angle of the z-axis relative to gravity is defined as theta (θ). The formula is shown below.

$$\rho = \arctan\left(\frac{A_x}{\sqrt{Ay^2 + Az^2}}\right) \quad (1)$$

$$\phi = \arctan\left(\frac{A_y}{\sqrt{Ax^2 + Az^2}}\right) \quad (2)$$

$$\theta = \arctan\left(\frac{\sqrt{Ax^2 + Ay^2}}{A_z}\right) \quad (3)$$

The acceleration, which is due to gravity, will be combined now. When the accelerometer is static. The resultant accelerations from the three axes will equal to 1g.

$$\sqrt{Ax^2 + Ay^2 + Az^2} = 1g \quad (4)$$

The formula stated above has been used in the fall detection system because it can obtain the acceleration data, the angle is of the y-axis relative to the ground, which is defined as Roll (ϕ), the angle of the x-axis relative to the ground, which defined as Pitch(ρ), and the angle of the z-axis relative to gravity which defined as theta (θ) easily by using a simple formula. By using the formula stated above, the fall detection system can use only one accelerometer to obtain the data needed.

3. METHODOLOGY

An IoT system for fall detection system is designed to fulfill the requirements and problem statement. This fall detection is designed to attach to a bicycle. This fall detection system can detect the fall of a cyclist by using an accelerometer. When a fall is detected, the GPS will locate the bicycle and the cyclist's location. The system will automatically send an emergency email containing the location of the cyclist and bicycle to the specific receiver to reduce emergency response time. In the design system, the services for fall detection, location, and emergency alerts have been implemented. A NodeMCU as shown in Figure 1 has been used as a microcontroller unit in the fall detection sensor. NodeMCU is an open-source and LUA programming language based on the firmware developed for the ESP8266 Wi-Fi chip. NodeMCU has been used in this fall detection because it has high features, low cost, and low power consumption.

Figure 1. NodeMCU ESP8266

A. Fall Detection System

A fall detection system requires some data to detect a fall or an object's motion. Acceleration data has become one of the most frequently used data to detect falls. The acceleration data have also been used to calculate roll angle. This fall detection system will require acceleration data to detect a fall. The acceleration data will help the system to determine the orientation of the cyclist and the bicycle. Based on previous research, accelerometers have been widely used in the fall detection system to measure acceleration. An accelerometer can measure the rate of change of the velocity of an object in all axes in 3-dimensional space. An accelerometer can be used to measure and analyze the body movement of the users by using an algorithm. An MPU6050 is a sensor module that can function as a 6-axis module, which is a 3-axis accelerometer and 3-axis gyroscope. It is a Micro-Electro-Mechanical System (MEMS) that can measure acceleration, velocity, orientation, and displacement. It also is a small size module and has low power consumption. It measures the rate of change in velocity, which is acceleration for each axis in a standard SI unit of meters per second square $[m/s^2]$.

B. Location Services

Location service is a service that provides geographic data and information to users. A GPS has been used as a location service in fall detection systems. GPS has been widely used to track the location of vehicles. The GPS will update the cyclist's current latitude and longitude position when every fall is detected. The latitude and longitude values will be sent to the microcontroller, and the microcontroller can edit the message and send it to a specific email. The message will contain a hyperlink to Google Maps utilizing the user's current coordinates. In this fall detection system, U-Blox Neo 6M module is used. This GPS module is a stand-alone GPS receiver with high performance as a positioning machine. The GPS module has to connect to satellites to activate the GPS module. Therefore, it must test an outdoor or empty space. The GPS module can be connected to any microcontroller, but in this fall detection system, the GPS module will be connected to NodeMCU.

The power input for the GPS module should be 5V. There is a memory chip installed in the GPS module; if the GPS module can't connect to the satellite, it will show the last position that can connect to the satellite. This GPS has to go through a cold start or hot start before connecting the satellite. The cold start timeframe is around 27 seconds, and the hot start timeframe is around 1s. During the testing period for the GPS module, the GPS module has placed near the window, and it required around 1 minute to connect to the satellite. When it is connected to the satellite, a red LED light will start blinking, indicating the GPS module has successfully connected to the satellite.

C. BLYNK

BLYNK is a new platform for IoT projects. BLYNK allows controlling and monitoring hardware projects from IOS or Android devices. BLYNK can control various micro-controllers such as Arduino, Raspberry Pi, and NodeMCU via the Internet. This application can create a human-machine interface or graphical interface by compiling and providing the appropriate address on the widgets. Users are required to create an account in BLYNK and select the microcontroller that is used in the project. An authorization key will send to the user's email. Various widgets are used in the BLYNK app in this fall detection system, including value display, notification, email, and map. Value display is used to display the value of latitude and longitude. The virtual pin is to exchange any data between hardware and the BLYNK mobile app. A software overview has shown in Figure 2.

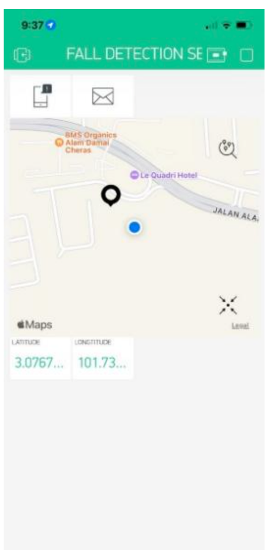


Figure 2. Software Overview

D. Prototype Development

An ESP8266 microcontroller is used and connected to an MPU6050 and a Neo 6M GPS module. The circuit diagram has shown as Figure 3.

A set of algorithms must be developed to fulfill the requirement of the fall detection system. The system must be able to detect a fall and send an emergency alert to the selected contact. When the system is powered on, the ESP8266 will automatically connect to the selected WIFI and BLYNK cloud. The smartphone will receive a notification alert to show that the WIFI is connected.

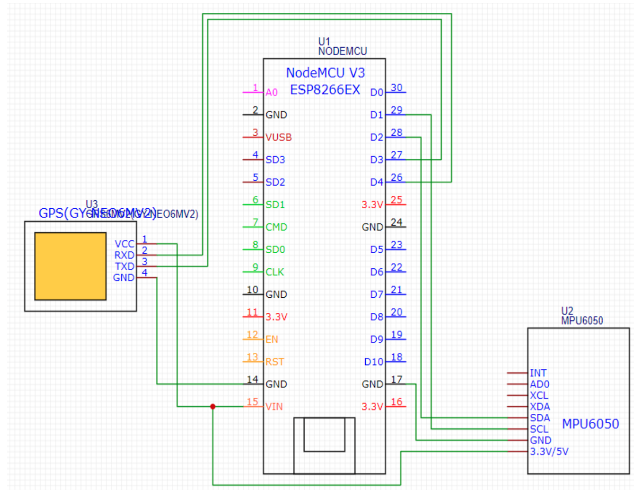


Figure 3. Circuit Diagram

The GPS will start to connect to the satellite and the accelerometer will start to record the acceleration reading. The acceleration value has also been used to calculate the roll angle value. If total acceleration is equal to 9 m/s^2, it means the bicycle is in static motion, because the only force is on the z-axis, which is a gravity force. The accelerometer will keep reading the value. If is greater than 9 m/s^2, it means the bicycle has started moving, and trigger 1 will be activated. The algorithm will start to calculate the roll angle (ϕ) of the bicycle. If the roll angle is greater than 60 degrees or below -60 degrees, it indicates a fall maybe occur. The inclination angle is set as 60 degrees because the angle has reached a critical situation as there is a high percentage that cyclist will lose their balance and fall from a bicycle. The bicycle will fall either to the left or to the right side rotating around the x-axis. If the roll angle is between 60 degrees and -60 degrees, the microcontroller will keep reading the data from the accelerometer and calculate the roll angle using the formulas. If the roll angle is greater than 60 degrees or below -60 degrees, the microcontroller will delay for 500ms and read the data from the accelerometer again. If the acceleration value is equal to or below 9 m/s^2, it means the bicycle has been in static motion and it means a fall occurred. If a fall is detected, the microcontroller will start to read the latitude and longitude values from the GPS module. The GPS module has to connect to a satellite to obtain the latitude and longitude values. After getting the latitude and longitude values, the microcontroller will connect with BLYNK and send an emergency alert to the smartphone. The algorithm flow chart is shown as Figure 4.

After several testing, the hardware parts are connected using a printed circuit board as shown in Figure 5. Acrylic is used as the casing of the system.

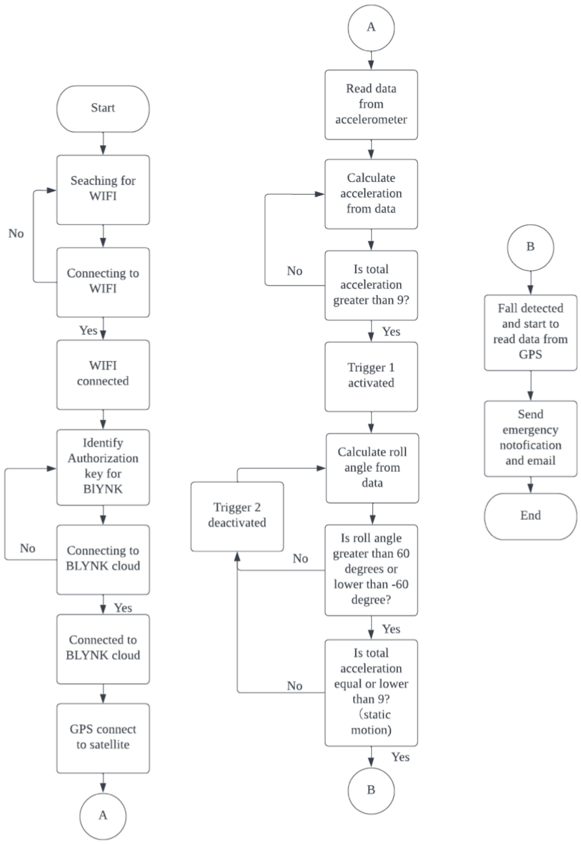


Figure 4. Algorithm Flow Chart

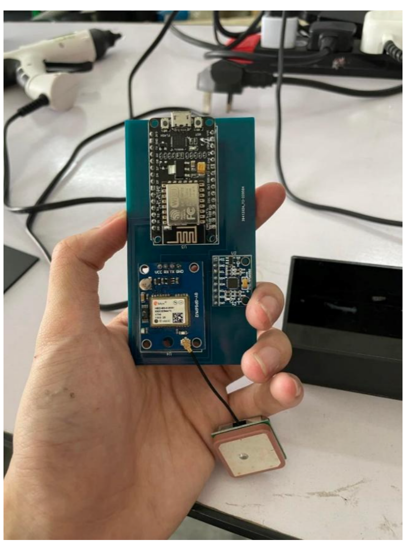


Figure 5. Fall Detection System

4. Result and Analysis

The experiment is carried out on asphalt roads. This experiment will take place over 15 seconds and will simulate the acceleration that occurs when riding a bicycle, starting to get imbalanced and eventually falling off a bicycle.

Based on Figure 6 the graph shows that the acceleration data maintain at 9m/s2 when the bicycle is in static motion. The acceleration data remain at 9m/s2 when static motion or no movement situation is because the only force that acts on the bicycle is the gravitational force.

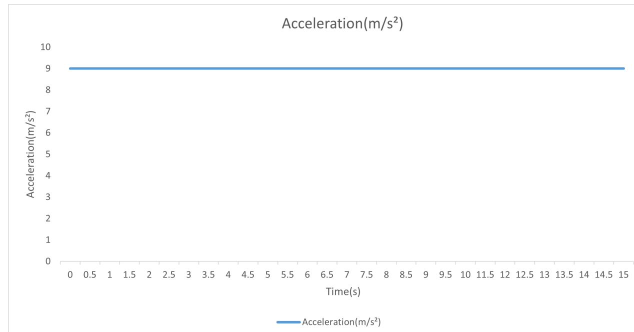
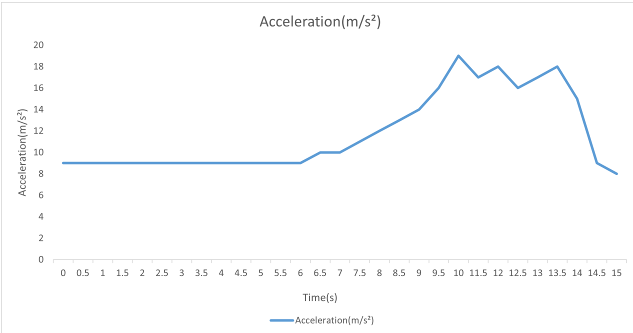


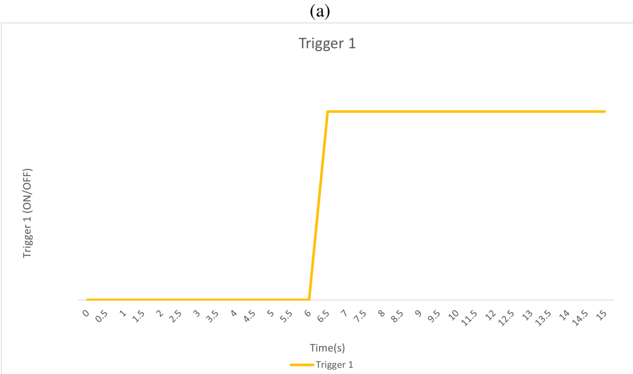
Figure 6. Acceleration data when bicycle is in static motion

Based on Figure 7, the bicycle remains in static motion, starting from 0s to 6s, which the graph 7a shows that the acceleration data is $9m/s^2$. The bicycle starts to accelerate at 6.5s, and the experimenter tries to maintain the acceleration data between 10 m/s^2 and $20m/s^2$. Since the acceleration data is over $9m/s^2$ starting from 6.5s, so trigger 1 has been activated, which marks as ON in the data shown in graph 7b. The acceleration data has been decreased to $9m/s^2$ at 14.5s, which shows that the bicycle is in a steady-state situation. The value of acceleration has decreased rapidly, indicating that there may be some falls occurring, and the bicycle has been in a no-movement situation.

Based on Figure 8, the bicycle has remained in a stable state from 0 seconds to 7s because the roll angle value has changed only slightly throughout that time which is shown in graph 8a. The bicycle begins to lose its stability at the 7.5s, as seen by a considerable increase in roll angle value and an indication that the bicycle is leaning to the right. Since the roll angle has reached 67.02 degrees, trigger 2 was activated at 10 seconds, as shown in graph 8b, because there is a strong possibility that the bicycle has begun to tilt to the right side aggressively, which may result in the rider losing control of the bicycle. Since the bicycle is still in the accelerating stage after 11.5s, trigger 2 has been deactivated. This means that the system will not detect a fall and will instead continue to analyze the data.

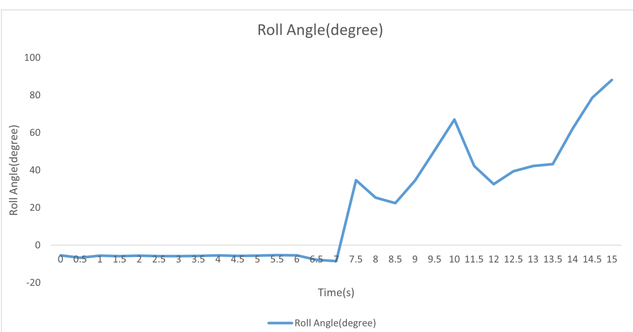


(a)

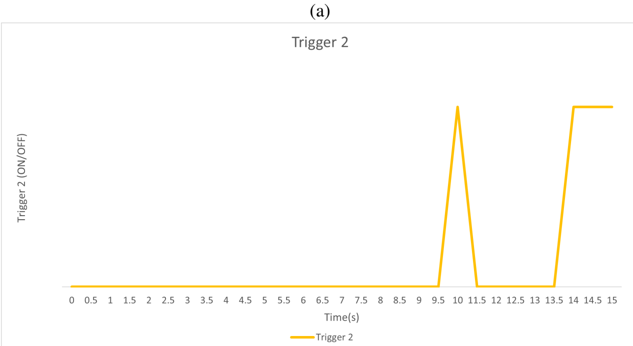


(b)

Figure 7. Response of (a) Acceleration Data. (b) Trigger 1 Data



(a)



(b)

Figure 8. Response of (a) Roll Angle Data. (b) Trigger 2 Data

Based on Figure 9, the fall detection feature has not been active since the beginning of the period shown by the graph (which reads as OFF). The fall detection will be activated and sensed as falling when it satisfies a few conditions, such as when there is an acceleration (trigger 1 activated), when the roll angle is greater than 60 degrees or lower than -60 degrees (trigger 2 activated), and when there is no acceleration after trigger 1 and trigger 2 have both been activated. These conditions will cause the fall detection to be activated and sensed as a fall.

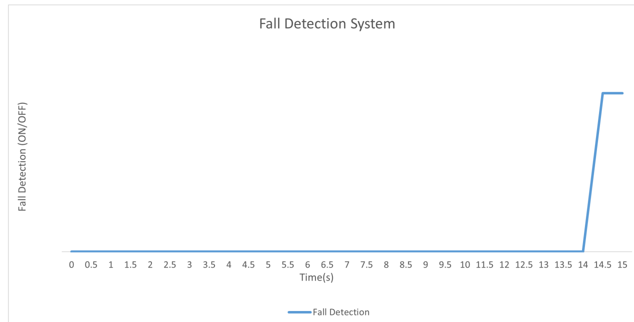
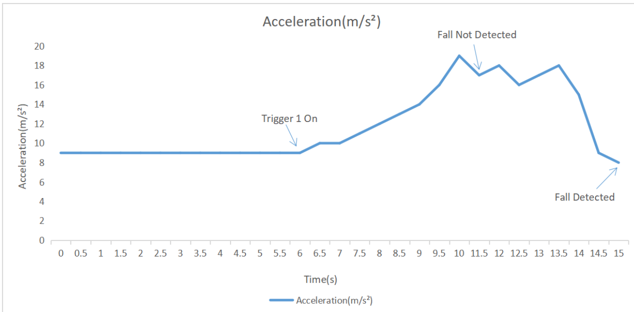


Figure 9. Graph of fall detected data

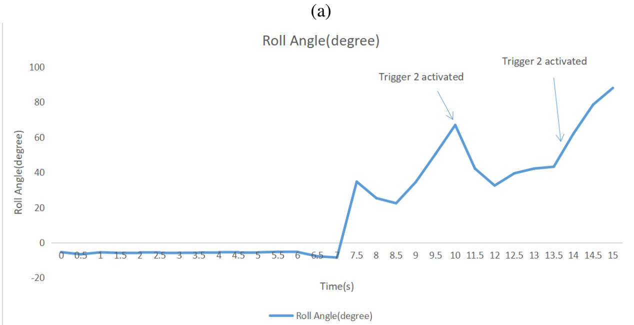
Based on the results of this experiment, as shown in Figure 10, trigger 1 is activated starting from 6.5 s as shown in Figure 10a, while trigger 2 is activated starts from 10 s as shown in Figure 10b. After both trigger 1 and trigger 2 have been triggered, the system will begin to receive acceleration data from the accelerometer. Since the bicycle has maintained its acceleration at 11.5 s, the system has determined that a fall did not take place and didn't detect a fall (marked as OFF) which is shown in Figure 10c. At the 14 s, both trigger 1 and trigger 2 were simultaneously triggered. However, there was no acceleration during the 14.5 s. Since the aforementioned requirements have been satisfied, the fall detection system has been enabled. As a result, the ON marking in Figure 10c indicates that the system has detected that a fall has taken place.

After the system has detected a fall, it will immediately send an emergency alert notice to the phone and an emergency email to the particular email address as shown in Figure 11 to notify the users who are associated with those addresses. There will be a link attached to the email and clicking on that link will take users to a Google Map that displays the location where the fall was detected.

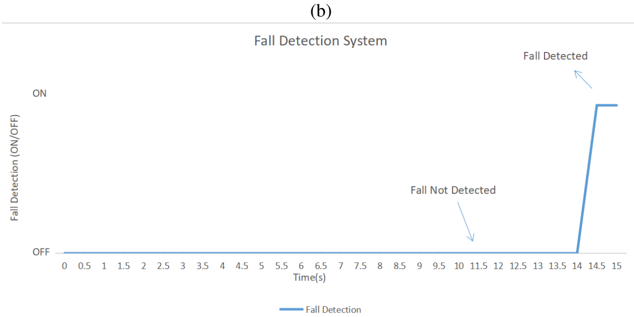
Within the scope of this fall detection system, the GPS location plays an important role. The GPS that is included in the fall detection system will allow the rescue crew to pinpoint the precise site of the accident. It is necessary to carry out a series of experiments to validate the accuracy of the GPS before attempting to validate its operational capabilities. In order to demonstrate the location where the accident took place, this experiment makes advantage of the link that was sent in the email. The user can view the location by clicking on the link, which will take them



(a)



(b)



(c)

Figure 10. Response of (a) Acceleration Data. (b) Roll Angle Data. (c) Fall Detection Data

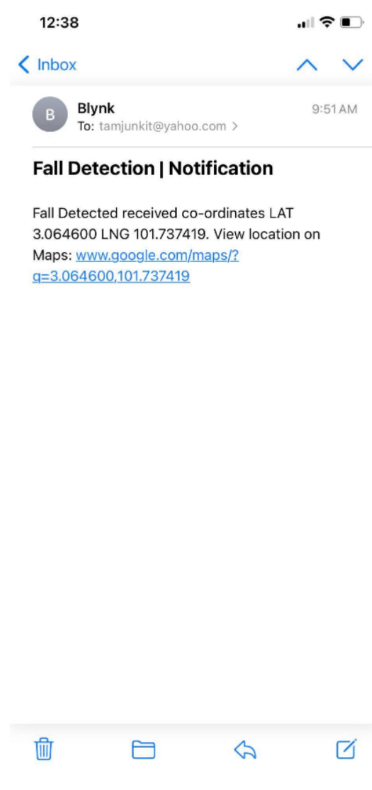


Figure 11. Emergency email alert

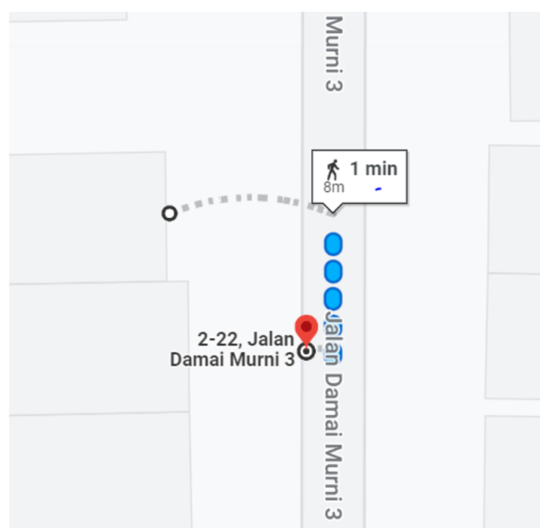


Figure 12. The Distance Between Two Location

to Google Maps. It has been determined with the help of Google Maps how far apart the location of the initial accident and the place described in the emergency email are shown in Figure 12.

The experiment has been completed, and the result can be seen in Figure 13. The distance of 10 meters has been determined to be the furthest one in this experiment, while the distance of 5 meters has been determined to be the closest one. The outcome of the experiment can be affected by several factors, the most important of which are the number of satellites to which the GPS can establish a connection and the placement of the antenna. This GPS may connect to as many as 22 satellites to provide an accurate location reading. The accuracy of the GPS can be determined if the antenna is installed in a spacious and wide area so that it may connect to a greater number of satellites.

5. Conclusions and Future Work

In conclusion, the fall detection system's prototype has been successfully developed, and a series of experiments have been carried out to test the functionality of the fall detection system. The fall detection system consists of an accelerometer, GPS module, and IoT. As a result, the fall

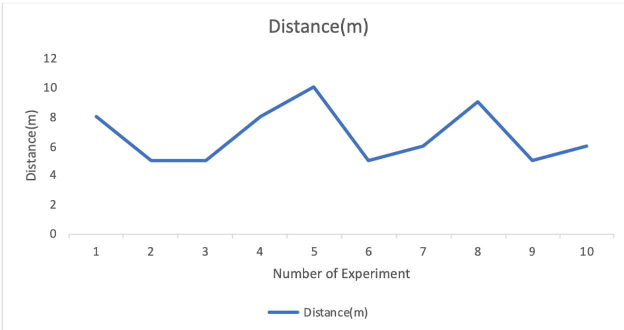


Figure 13. Graph of GPS Result

detection system has successfully detected a fall and the GPS produced an accurate reading of the fall's real-time location. Then, the emergency alert was sent immediately to the selected contact on the smartphone. It will help the community by reducing the emergency response time and increasing the probability of preserving a person's life.

In future works, powering up the fall detection system using dynamo is recommended. The dynamo will convert the kinetic energy to electrical energy to power up the fall detection system. The generated energy by dynamo is renewable energy which will help to preserve the environment. Furthermore, it is recommended to conduct a comparative analysis with existing studies to enhance the findings.

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