ZIGBEE-BASED SMART FALL DETECTION AND NOTIFICATION SYSTEM WITH WEARABLE SENSOR (e-SAFE)

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Abstract

Fall is one of the serious health issues among elderly population in Malaysia. In the event of a fall, a strong impact may be inflicted on the elderly causing severe injuries or even death. Another research by the National Institutes of Health found that 67% of elderly who fall and fail to seek help within 72 hours are unlikely to survive. Current Personal Emergency Respond System (PERS) often employs the use of a manual emergency button. However this approach may not be useful if the fall victim become unconscious or even not be able to move to reach the emergency button. In addition, such as this approach also requires more time and inadequate to notify and seek for immediate help. This paper attempts to design and implement a smart fall detection system for real time notification known as e-SAFE. This system will automatically detect a fall and notifies the incident instantly to internal and external correspondence. The e-SAFE equipped with a wearable accelerometer sensor, microcontroller, ZigBee transceiver module and Global System for Mobile communications (GSM) device. The in-house correspondence will be notifies though the ZigBee technology, meanwhile the external correspondence will be notified through GSM. Once a fall has been detected by e-SAFE system, a Short Message Service (SMS) and an E-mail will be sent to predefined contacts which is stored in the system. This system will provide a path toward independent living for the elderly while keeping them save.

Index Terms: *Emergency Respond, Wearable Accelerometer Sensor, ZigBee, GSM, SMS, E-mail.*

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1. INTRODUCTION

A study by private hospitals have shown that the number of elderly falling down increased by 27% from 2007 to 2008 [1] and 66.7% of the cases happened at home [2]. In the event of a fall, a strong impact may be inflicted on the elderly causing severe injuries or even death. Another research by the National Institutes of Health found that 67% of elderly who fall and fail to seek for help within 72 hours are unlikely to survive. On the other hand, the fall victim is nearly six times more likely to survive if help can be attained within one hour [3]. Thus, this studies shows that the immediate emergency respond is crucial in order to increase survival rate of fall cases greatly.

Current Personal Emergency Respond System (PERS) often employs the use of a manual emergency button. However this approach may not be useful if the fall victim become unconscious or even not be able to move to reach the emergency button. In addition, such as this approach also requires more time and inadequate to notify and seek for immediate help.

Therefore an automatic fall detection and notification system (e-SAFE) is proposed in order to instantly notify the fall incident to immediate family members or caretaker so that they can response quickly to provide immediate help to the victim. This is more appropriate solution especially to the elderly people who are living alone at home.

The system consists of both hardware and software. The microcontroller will accept an output from a 3-axis accelerometer which is used to detect a fall. When a fall is detected, a triggering signal will be transmitted to the base control to notify the incident to predefined contacts.

Transmission and reception of the triggering signal is performed by X-bee PRO. The main reason of employing X-bee PRO technology is due to its low power consumption and the ability of transmitting range up to 90 meter in indoor environment [4].

The base control that receives this triggering signal will proceed to send the alert notification to the predefined contact through SMS and email immediately. Although this system cannot prevent falls from happening, it will reduce the chance of the fallen victims being left untreated for an extended period of time by instantly informing others about the fall incident.

2. CHARACTERISTIC OF FALLS

Falls in indoor environment can be classified into three types: fall from standing, fall from walking and fall from sitting. Each type of fall has its own characteristic which will be further explained as below.

2.1 Falls from Standing

This fall will be occurred within 1 to 2 seconds. It is classified as a fall which is happened from initially standing to sudden fall. The person normally falls in one direction. While falling down, the head undergoes free falling. The person will end up lying on the floor. Final position of the person who falls is within his/her standing point to the radius of his/her height.

2.2 Falls from Walking

This fall usually will be happened within 1 to 3 seconds. It is classified as a fall when the person is initially walking with certain acceleration and then involved in sudden fall. The person normally will falls in the direction of walking. Similar to fall from standing, the person's will end up lying on the floor. The position of the person who falls will be within his/her standing point to the radius of his/her height.

2.3 Falls from Sitting

This fall is best described as someone who initially sitting on a chair and then involved in sudden fall. It usually will take around 1 to 3 seconds and is considered dangerous because this person's head might hit with the chair before it hits the ground. Consequently, the person ends up lying on the floor or nearby to the chair.

3. RELATED WORKS

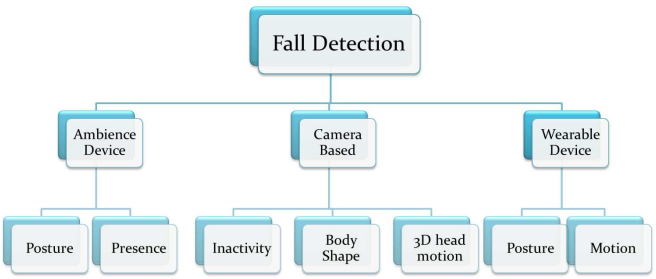

Fig -1: Hierarchy of fall detection approaches.

Fig. 1 shows the hierarchy of fall detection approaches. One of the common characteristic of all these systems are their general structure of the overall system which as illustrated in Fig 2.

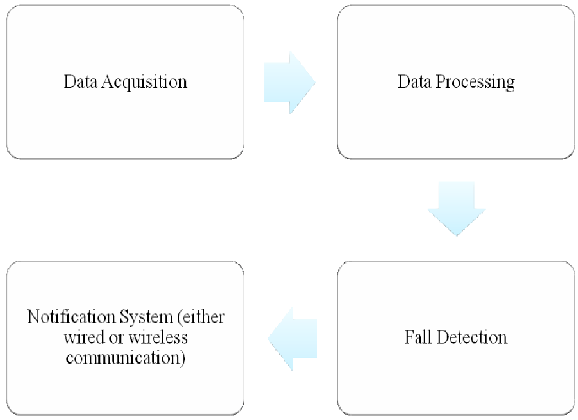

Fig -2: General structure of fall detection and notification system.

Data acquisition is performed by a single sensor in a simpler system or multiple sensors or cameras in a more complex system. Its function is to collect signal and video data to be processed. There are several methods is used to detect the falls. Some of it is acceleration threshold, image processing, database-based etc.

3.1 Camera-Based Approach

Camera-based approach utilizes one or multiple fixed-position cameras to detect the posture and motion of the person to determine a fall. Camera-based approach is able to detect multiple events simultaneously and is the most straight forward way to detect a fall. There are several algorithms is developed on camera-based approach such as 2D body orientation change analysis, inactivity detection and 3D head motion analysis [5] & [6].

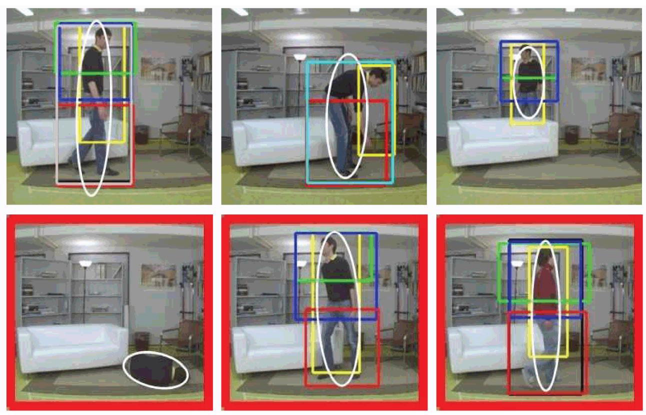

Fig -3: Camera-based approach.

2D body orientation change analysis is based on the principle that the shape of a falling person will change from standing to lying down. On the other hand, 3D head motion analysis tracks the position of the head to determine a fall. Nonetheless, there are many problems associated with camera-based approach such as selecting an optimum resolution of video, changes in room lighting condition causing difficulties in image processing and daily activities and movement of human that might be confused with a fall [7].

Zambanini et al [8] proposed a fall detection system with low cost and with low-resolution cameras. Their goal is to invent low cost fall detection system with high accuracy that can be affordable by everyone to use. The authors have proved that the fall detection system can achieve better accuracy of fall by using low spatial resolution and low frame rate cameras.

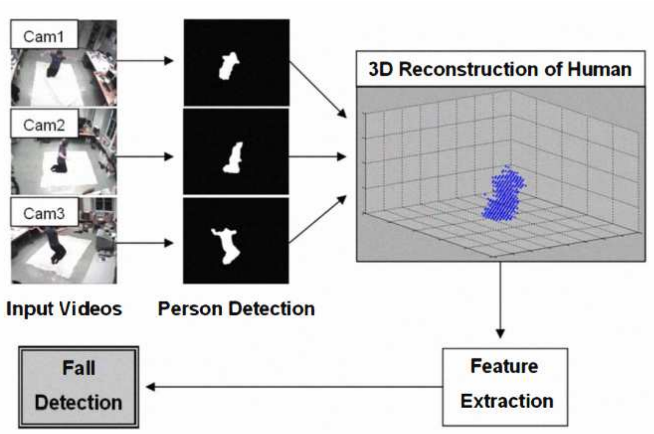

Fig -4: Description of fall detection by Zambanini (Figure courtesy of [8]).

Shaou-Gang Miaouet al [10] proposed small fall detection system using Omni-camera to capture 360˚ image of a person. The chances of blind spot can be eliminated by using this approach. Other parameters that took into consideration are the weight and the height of fall victim. Hartmann et al [11] also developed a similar system based on the principle of body movement.

3.2 Ambient Device Approach

Ambient device approach is installing multiple sensors in the indoor environment to collect data of the user [12]. Usually for ambient approach, a pressure sensor will be used to detect the presence and the fall of the user.

Zigel et al [13] has developed a fall detection system through vibration sensors. The system is equipped with floor vibration sensor and also microphone. It uses the concept of signal processing to detect fall. This type fall detection system is more suitable to be implemented in washroom and private room in which camera based approaches is not suitable to use.

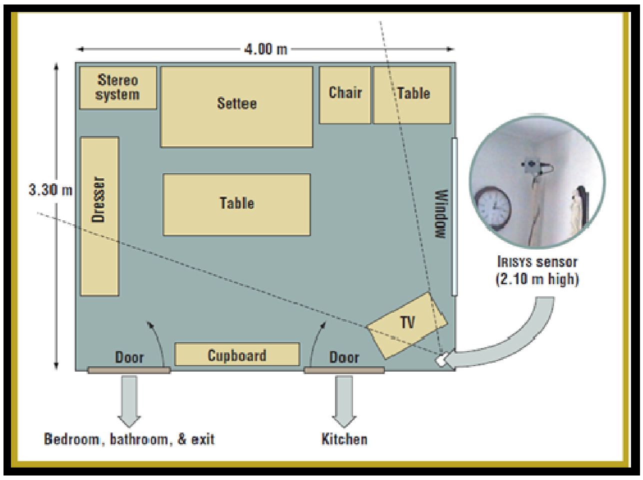

Fig -5: The setup for the field trial of the SIMBAD prototype.

The dotted lines illustrate the sensor's approximate field of view (Figure courtesy of [14]). Sixsmithet al [14] developed a SIMBAD (Smart Inactivity Monitor using Array-Based Detectors) by using a wall-mounted IRISYS (Infra-Red Integrated Systems) sensor to detect a fall. It can locate and track a thermal target which is moving within the range, provide the information such as size, location, and velocity of the person.

3.3 Wearable Device Approach

The wearable device approach is an embedded sensor device that can be worn on the user's body for detecting the posture or motion of the user and using a suitable algorithm to identify a fall [16].

Bourke et al. [17] developed a custom vest with embedded sensors to detect fall. They also designed a threshold-based tri-axial accelerometer fall detection algorithm which can achieved accuracy of more than 90%. However, during the test, there were false positives and false negatives. Anyway, this approach looks promising due to its high recorded accuracy.

Almeida et al [18] developed a walking stick that is able to detect fall by integrating a gyroscope in the stick. Once the stick has fallen, it assumes that a fall has occurred. However, the drawback of using such device is that user has to bring the walking stick all the time and it might not be effective to detect fall.

Jeon et.al [19] developed a Personal Emergency Response System (PERS) that uses a 3-axis accelerometer to detect fall and generates the alarm on the Personal Digital Assistant (PDA). Once a fall has been detected, an alarm will be generated. If the user does not respond to the alarm, the system will then classify the situation as an emergency and notify the incident to the emergency center.

Fig -6: Walking stick prototype with gyro and Atmel EB63 evaluation board (Figure courtesy of [18]).

Halo Monitoring Company invented a fall detection system what is called as "panic button". The device is a wristwatch with a button where user has to press the button in case of an emergency. The main problem is that it does not have the automatic notification feature which is very crucial if the victim become unconscious.

5. DESCRIPTION OF e-SAFE SYSTEM

There are many fall detection systems is already available in the market as per discussed earlier. However, its drawbacks of the available systems lead us to propose a novel system called ZigBee-Based Smart Fall Detection and Notification System with Wearable Sensor (e-SAFE).

The e-SAFE system is embedded with a sensor to sense different types of motion. Thus, e-SAFE sensing device will use a tri-axis accelerometer which is called as ADXL335. It is a small, thin, low power, 3-axis accelerometer with signal conditioned voltage outputs. It also able to obtain acceleration values from 3 different axes (X, Y and Z). ADXL335 measures acceleration with a minimum full-scale range of ±3 g. It suits with project needs as it can measure the dynamic acceleration resulting from motion, shock, or vibration [21]. As one of the products in e-Textile LilyPad, it is designed to be sewn or stitched on garment easily. Fig 10 shows the image of ADXL 335.

Fig -10: Image of ADXL 335 and embedded Lilypad ADXL335

Once the power of e-SAFE is switched on, the accelerometer will start do the sensing and 3 analog outputs of X, Y and Z axes will feed to the e- SAFE microcontroller. The process flow is as shown in the Fig.11.

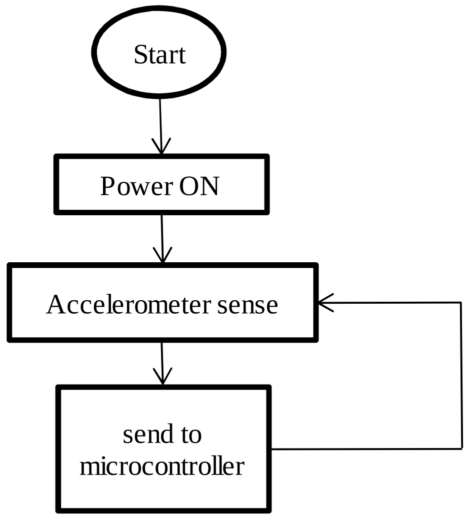

Fig -11: The operation of accelerometer

As shown in Fig 12, once the e-SAFE system has been activated, the microcontroller will start to sense the incoming analogue input from the accelerometer. The microcontroller will change the analogue input to digital input using the built in ADC. Then, the microcontroller will analyze the received data by using developed algorithm to detect the fall event. Once a fall even is detected, it will send a signal and string to XBee.

Instead using other available wireless transmission devices, the e-SAFE system employs ZigBee technology for the purpose of data transmission. This is due to its reliable data transmission among devices, relatively low cost, low power consumption, suitable for indoor applications and its compatibility to work with almost all microcontrollers.

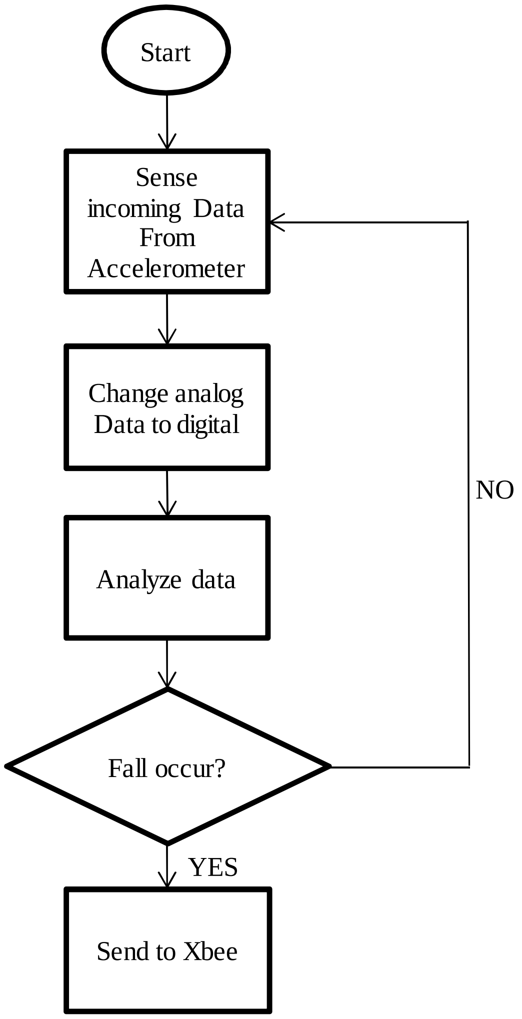

Fig -12: The operation of microcontroller

When e-SAFE system is switched ON, XBee will keep sensing the incoming signal from the microcontroller. Once a signal is received from the microcontroller, XBee will transmit the data to the receiver. Fig. 13 depicts the flow of XBee transmitting node to make a decision to transmit the datal to XBee receiver. On the other hand, The XBee receiver will continuous sense data from the transmitting node and pass the receive data to base controller as depict in Fig. 14. Once the base station received the triggering signal, then it will trigger the GSM to send out an alert message.

The e-SAFE system also equipped with GSM modem as mentioned earlier. The GSM is a wireless modem that sends and receives data through radio waves instead of a fixed telephone line. The operating frequency of the GSM is 900 MHz or 1800 MHz bands.

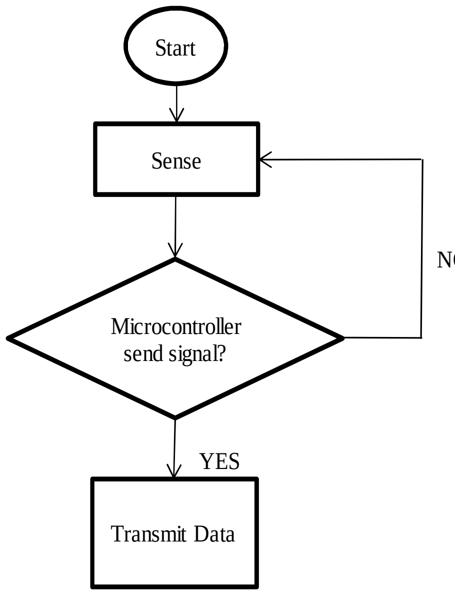

Fig -13: The operation XBEE in transmitting the signal

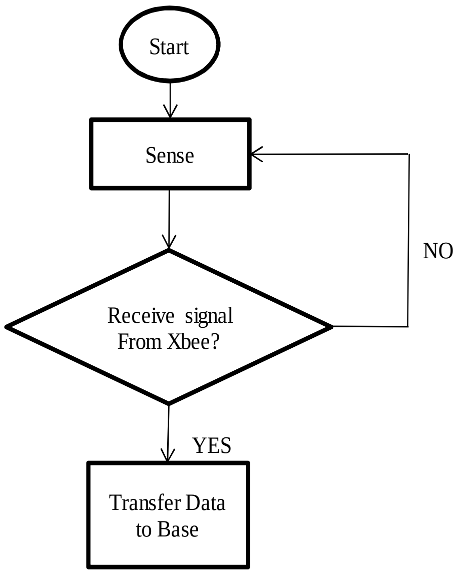

Fig -14: The operation XBEE in receiving the signal

The GSM will wait for the instruction from base controller to send out the alert message. It will send out an alert message once it is triggered by base controller. Fig.15 depicts the operation of GSM modem in sending out the alert notification to predefined contacts in the e-SAFE system. The alert notification will be received though SMS and E-mail.

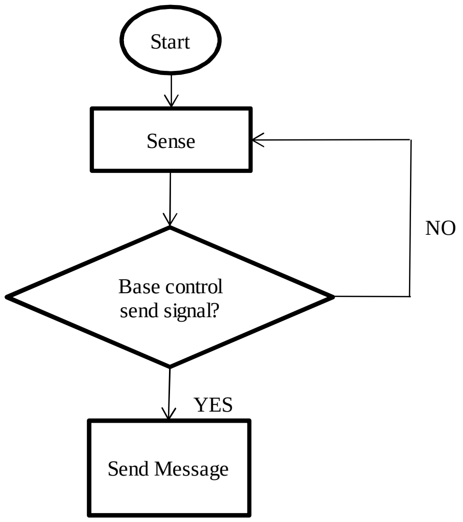

Fig -15: The operation GSM in sending out the alert message

6. The e-SAFE SYSTEM DIMENSION

The e-SAFE product dimension is as shown in Fig. 16. Its dimension is 12cm x 3cm x 7cm (length x width x height) which is fitting the profile of lightweight, small and easy to carry around.

Based on analyze that we have conducted, the best position for the device to be attached in our body is the waist. This is to because waist has the lowest extreme body movement. Even though the analysis obtained that the chest is guaranteed low possibility of false alarm, but it is extremely uncomfortable to place it over there.

Fig -16: The e-SAFE product dimension

7. THE BASE STATION OF e-SAFE SYSTEM

The base station of e-SAFE system is created using Visual Basic 2010. This windows application gives the flexibility to the user to enter their particulars such as the username, phone number and email address. The GUI which is developed is easy to use and can store up to 3 users at once. If a fall has detected, the developed GUI will act accordingly to send the instruction to GSM for send out the alert message. Fig. 17 shows the main window of GUI for e-SAFE system.

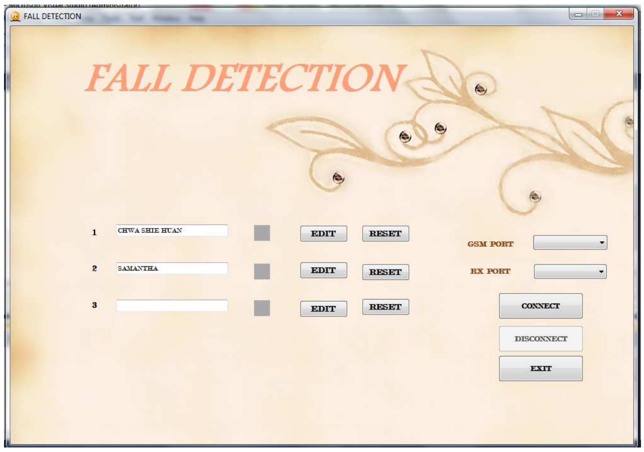

Fig -17: The main window of GUI application

Fig -18: The User information windows

Fig. 18 shows the user's information window that created to store the particulars of the recipients who will receive the alert message. The system can store up to 3 predefined contacts. All this contacts will receive the alert message when the fall incident happens. This information will be saved in the system and can retrieve easily whenever needed.

CONCLUSIONS

ZigBee Based Smart Fall detection notification system known as e-SAFE is a low-cost, reliable and accurate fall detection system that equipped with wearable accelerometer sensor, microcontroller, ZigBee transceiver module and Global System for Mobile communications (GSM) device. It also has integrated with the GUI to receive the detection from controller and send out the alert notification to predefined contacts. The e-SAFE provides a path toward independent living for the elderly while keeping them save. Although this system cannot prevent falls from happening, it will reduce the chance of the fallen victims being left untreated for an extended period of time by instantly informing others about the fall incident. In addition to this, the functionality of e-SAFE also can be further improved by adding extra features to make complete health monitoring system. It can be further enhanced to monitor heartbeat, blood pressure, body temperature and etc. A comprehensive and complete health monitoring system is can be developed by adding these features in e-SAFE system.

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