New Approach for Fall Detection System Using Embedded Technology

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***Abstract*— Elderly Fall accidents are one of the main causes of deaths due to fractures caused by collision with the ground or hard obstacles. This research paper aims to develop an intelligent fall detection system to detect the user fall and alarm the caretaker for a fast response. The early response of the caretaker to the alert will keep a high chance to save the life of the victim. In this paper, wearable low-cost fall detection and alarming system for the elderly has been proposed. a novel approach has been used to reduce the false-positive fall alarm. The user motion tracked using a sophisticated orientation detection module to detect user orientation in different output forms. In case of any abnormal orientation data values of the user, the system will send an alarm message via Wi-Fi and GSM to the caretaker. The system design considers a simple and low-cost design with acceptable power consumption rate. The system consists of a Wi-Fi-based microcontroller, and two orientation detection modules, and a GSM module. The system is designed for the user to wear in the waistline by installing it with the waist belt. The system used a rechargeable pin-type lithium-ion battery as a power source.**

Keywords— ***Fall Detection; Wearable Device; Orientation Detection; Internet of Things; Embedded System.***

I. Introduction

Falling accidents are one of the biggest causes of death for elderly peoples. Based on the World Health Organization WHO website, the falling is the second reason for death for more than 640000 persons die each year. Unintentional injury resulting from a fall accident is very critical for the elderly and need fast response to avoid complications that lead to death. The biggest percentage of victims of the previous statistics are adults older than 65 years. [1]

As a fact that a lot of elderly around the world living alone, and the danger of facing falling or any other accident is highly possible. The worst case happened when nobody knows about this critical accident because the victim is weak and may lose consciousness or be unable to call for help. Many researchers work in this domain to help elderly alarm caretakers in case of fall accident happened. Several approaches have been used to implement the fall detection and alarming system. Generally, there are three main strategies used which are, camera-based, wearable sensor-based, and ambient sensor-based fall detection systems.

Camera-based systems mainly used multi-cameras in a specific location to capture the user motion. The captured image will be processed by an image processing algorithm to detect and recognize the fall condition. Most of the camera-based systems have the problem of the user privacy obtrusion.

Fouzi Harrou et al., proposed a camera-based fall detection system. A statistical approach has been used for classified and detected the fall event using the generalized likelihood ratio (GLR) and support vector machine (SVM). The used strategies increase the accuracy of correct fall detection and reduce false-positive fall detection with the limitation of using in the indoor environment. [2]

Erik E. Stone et al., Proposed Kinect camera-based fall detection system. The system has two stages to detect a fall accident. the first stage collects the depth user information collected by the Kinect camera over time and characterize the vertical state of the user. The second stage uses a decision tree algorithm to recognize the fall on the ground event. [3]

Another group of researchers used an ambient sensor-based fall detection system. In this method, a sensor network has been used to collect the fall information without attached the sensors to the user body.

Xiuyi Fan et al., proposed an infrared array sensors-based fall detection system. The system using some deep learning methods such as gated recurrent unit models and long-short-term-memory to enhance the performance compared with previous work using the same sensors type. [4]

Liang Liu et al., proposed a doppler radar sensor-based fall detection system. The system used a data fusion algorithm between the motion sensor and doppler radar to enhance the detection of fall accidents and reduce the false-positive error. [5]

A wearable sensor has been used to implement a fall detection system. Several approaches using different types of wearable sensors attached to different body parts such as head, waist, chest, and foot used to acquire the required motion information that used to recognize the fall condition [6-11]. Most of the wearable sensor-based systems used accelerometer, gyroscope, and magnetometer individually or combined to acquire user motion information. [12-13]

In this paper, the design, implementation, and testing of smart wearable fall detection and alarming system have been proposed. The system design takes into consideration the parameter of low cost, small size, and lightweight. A novel approach based on using two orientation detection sensors with OR-AND logic algorithms for the wearable sensor-based fall detection system has been successfully used. The system processes the orientation data from two different orientation detection modules which are BNO055 and BMI 160. The fall case will be tracked by both modules. The combination of the two different orientation sensors with the OR-algorithm enhances the performance of the system and reduces false-negative errors (the system does not recognize the fall condition). The use of the AND-algorithm will reduce the system accuracy but at the same time, it reduces the false-positive error hardly.

The system built in a simple three layers construction. The first layer is the input layer which is responsible for the data acquisition from the user body. The second layer is the main processor which is responsible for data processing and decision making. And the third layer is the output layer which is responsible for sending the alarm to the caregivers. The following sections will explain the system design and components in detail.

II. METHODOLOGY

The system consists of three main layers, which are, the input layer, the processing layer, and the output layer. The system block diagram is shown in Fig. 1. The input layer is responsible for the orientation data acquisition of the user body. The acquired data and information will be sent to the main processing unit for classification and generation of the right decision. Then If the main unit detects any situation required alarming the caretaker, it will send the information to the output layer. The output layer will send the alarm information to two different receptors which are the caretaker phone via SMS message and the caretaker Email. All system layers and their contents of sensors and modules will be detailed in the following sections.

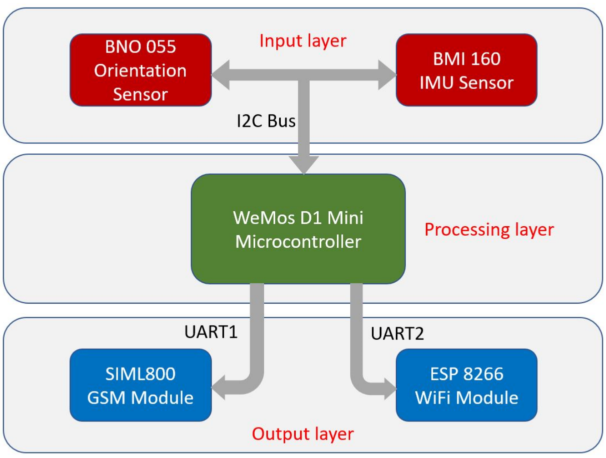

Fig. 1: Block Diagram

A. *The Input layer*

The input layer consists of two orientation detection modules. Both of them used the MEMS sensor to detect body orientation. The first unit is the Atmel BNO055 Xplained Pro module which is built based on the Bosch BNO055 System in Package (SiP). It consists of three triaxial MEMS sensors which are, an accelerometer, a gyroscope, and a magnetometer combined with a 32-bit ARM microcontroller. The BNO055 can communicate with any host processor using the I^2C or UART bus. The body orientation can be provided in several forms like Euler angles, Quaternion, Linear acceleration, and Gravity vector. In the proposed system the I2C bus has been used for communicate between the BNO055 and the host processor and the Euler angles have been used for representing the body orientation in the form of pitch, yaw, and roll Euler angles. Fig. 2 shows the used BNO055 module.[14]

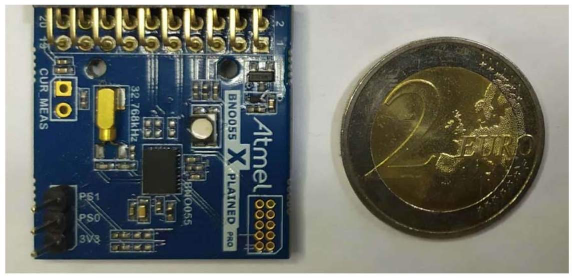

Fig. 2: Atmel BNO055 Xplained Pro module

The second module is the BMI160 from Bosch sensor technology, Germany. It is an Inertial Measurement Unit IMU that provides real-time accurate sensor data for body orientation. It is consisting of an accelerometer, and a gyroscope, and communicating with a host processor using the I^2C bus. [15]. Fig. 3 shows the Bosch BMI160 IMU unit.

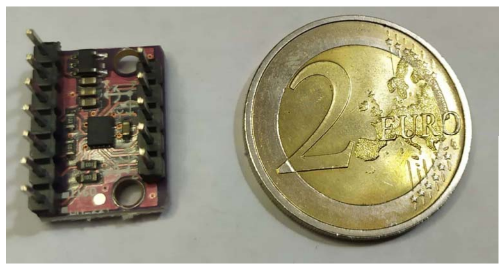

Fig. 3: Bosch BMI160 IMU unit

B. *The Processing Layer*

The processing layer of the system is the low-cost WeMos D1 Mini IOT microcontroller. It is an ESP8266-based microcontroller with a Wi-Fi facility. The WeMos uC has the required I2C and UART communication buses to communicate with input and output layers. Also, it is allowing the system to have wireless communication with the available Wi-Fi network. Fig. 4 shows the WeMos D1 mini microcontroller.

Fig. 4: WeMos Esp8266-based microcontroller

C. The Output Layer

The output layer consists of two units which are the Esp8266 Wi-Fi module and the SIM800L GSM module. The output layer is responsible for receiving the alarm message from the processing layer and send it to the caretaker. The output of the Esp8266 is a message to the caretaker Email. The message will be sent via a full TCP/IP stack. The second form of alarming will be an SMS message to the caretaker mobile via the SIM800L GSM module. Fig. 5 shows the SIM800L GSM module.

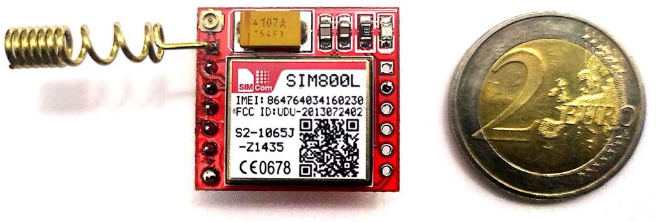

Fig. 5: SIM800L GSM module

The System components are powered by a 3.7V, 5.1Wh lithium-ion battery. The battery used is sufficient to operate the device efficiently for one day. Fig. 6 shows the used battery.

Fig. 6: System battery

III. System Description

The user body movement is tracked by the input layer. To achieve this purpose, two-directional tracking units were used from the Bosch Sensortec, Germany, and they were BNO055 and BMI160. Both modules have a triaxial accelerometer and triaxial gyroscope which have been used by the processing layer algorithm to detect the fall accident. The data is captured by these two units and sent to the processing unit using the I2C bus. The BNO055 module has the I2C address (0x69) and the BMI160 has the I2C address (0x68) and the data from each unit acquired by the processing unit using I2C read function for a specific I2C address.

The processing unit (WeMos D1 Mini microcontroller) received the acceleration data and the angular orientation from both BNO055 and BMI160 registers, and calculate the acceleration and body orientation for each sensor. The decision for sending an alarm to the caregiver is depending on the values of the acceleration vector and the orientation vector of both sensors and can be calculated as:

$$Acc_1 = \sqrt{ax_1^2 + ay_1^2 + az_1^2} \qquad \ldots(1)$$

$$Acc_2 = \sqrt{ax_2^2 + ay_2^2 + az_2^2} \qquad \ldots(2)$$

$$G_1 = \sqrt{gx_1^2 + gy_1^2 + gz_1^2} \qquad \ldots(3)$$

$$G_2 = \sqrt{gx_2^2 + gy_2^2 + gz_2^2} \qquad \ldots(4)$$

Where Acc_1, Acc_2, are the acceleration vectors of the BNO055, and BMI160 sensors respectively, and G1, G2, are the orientation vectors of the BNO055, and BMI160 sensors respectively.

When the processing layer detects a value of acceleration above the specific programmed threshold it will check the body orientation for short time window before the threshold and if both acceleration and body orientation are brocks the thresholds an alarm SMS message and an email will be issued and send to the output layer to send it to the caretakers phones and PCs.

As the WeMos D1 Mini has only one hardware serial port, the soft serial library has been used to send the SMS message and the Email to the Esp8266 and SIM800l modules. Fig. 7 illustrates the procedure of system activation.

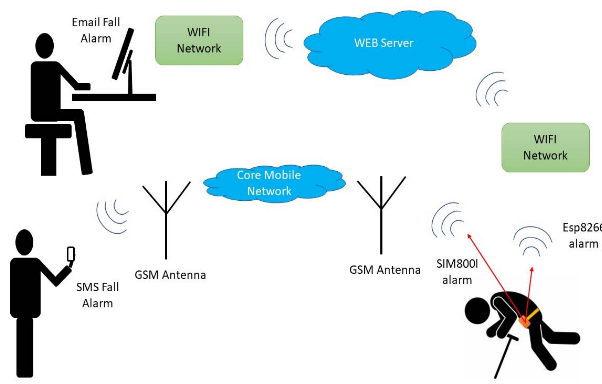

Fig. 7: Procedure of system activation

1) System algorithm:

The proposed system has a novel implementation by using two orientation detection sensors instead of one in most previous works. The advantage of this addition is to give the system the chance of cancellation of false-positive errors (false alarm). The algorithm starting by initialized the registered of the two orientation modules BNO055 and BMI160. In the next step, the host processor read the acceleration values from the specific accelerometer register of both modules to calculate the acceleration vector Acc1 and Acc2. Then the same procedure repeated with the gyroscope registers to get the rotation angles gx, gy, and gz to calculate the orientation vector G1 and G2. If the magnitude of the acceleration vector Acc1 and Acc2 are bigger than the lower and upper thresholds then the algorithm checks if the orientation has been changed at the past 500ms, and if all these conditions have been achieved then the algorithm will send the alarm message via the SMS and email facilities.

The algorithm starts picking up the acceleration and the body orientation from both sensors. There are two scenarios when using two orientation sensors, the first is using OR logic condition, and in this case, the algorithm will activate the alarm status when any one of the orientation sensors passed the thresholds. In this scenario, the chance of false-positive error will be more, and the success ratio will be higher.

The second scenario is the use of AND logical condition, and in this case, the system will activate the alarm status only when both orientation sensors pass the fall thresholds. In this case, the false-negative errors will be increased and the chance of false alarm, as well as the false-positive error, will be hardly eliminated and this is very important in biomedical and rehabilitation systems. [16-18]

When the system detects fall conditions, the processing layer will send two kinds of alarm. The first alarm is an SMS message sent to the smartphone of the caregivers. The caretaker has already stored the number of his patient so he can direct response to the fall alarm. The system can send a message warning of the patient falling to several recipients according to the user's desire. Fig 8. Show a screenshot of the caretaker phone alarm message.

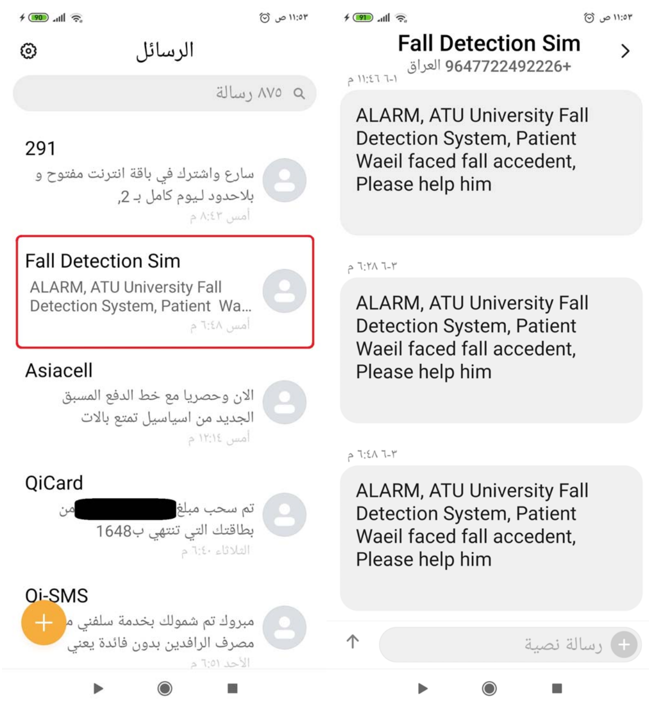

Fig. 8: SMS alarm message screenshot

The second type of alarm is done by sending an Email via the WIFI network using the SIM800l GSM module. The system sends the email request to the WEB server which sends the Fall-alarm email to the caregiver. The system can send multiple Fall-alarm emails to several caregivers according to the user's desire. Fig. 9 shows a screenshot of the caregiver PC includes the fall-alarm Email.

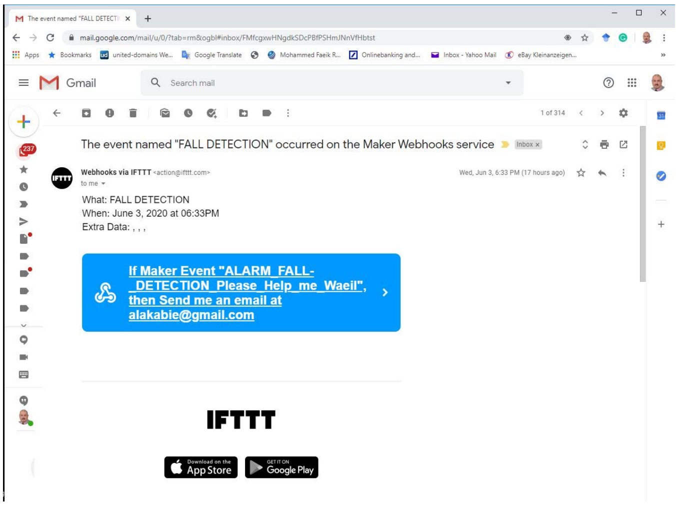

Fig. 9: Email alarm message screenshot

IV. Experimental Results

All the system component has been assembled in 10cm×5cm holder which is designed to fix on the waist belt. The orientation sensor has been tested individually and with AND-OR algorithms. Because of the spread of the Corona pandemic, the art of testing the device was conducted at home by only three people as a preliminary test. A twenty-five-centimeter squishy mattress is used to protect users from the risks posed by a fall. Each person has performed a fall test ten times for each sensor individually and with both sensors (AND-OR logics) in 4 fall situations which are, fall-forward, fall-backward, fall-left side, fall-right side. Table 1 explain the test result for the BNO055, BMI160, and both with AND-OR algorithms.

Table 1: Test of the system

Sensor	User	Front	Back	Left	Right
BNO055	1^{st} user	7	9	8	9
	2^{nd} user	8	10	9	9
	3^{rd} user	10	9	9	8
BMI160	1^{st} user	8	10	9	10
	2^{nd} user	9	9	9	8
	3^{rd} user	8	8	9	9
AND	1^{st} user	8	9	8	9
	2^{nd} user	8	10	8	9
	3^{rd} user	8	8	8	9
OR	1^{st} user	10	10	10	10
	2^{nd} user	10	10	10	10
	3^{rd} user	10	10	10	10

The results in table 1 revealed that the BNO055 module test has an accuracy of 87.5%, and the BMI160 module has an accuracy of 88.4%, and the test of the AND-algorithm has the accuracy of 85%, and the last OR-algorithm test shows 100% of success fall alarm. The result shows that the use of two orientation detection sensors can improve the accuracy of the system up to 100% present which is ideal for the required goal.

V. Conclusions

In this paper, the design and primary testing of IoT controller-based fall detection system have been proposed. The system design used a new approach by using two orientation sensors to detect the fall condition instead of using only one sensor in a traditional system. The system tests revealed that the use of two sensors with OR-algorithm has 120/120 success alarm trigger vis 105/120, 108/120, 102/120 respectively for individual and AND-algorithm testes. The primary tests show that the system accuracy can be improved using the OR-algorithm which is combined the two orientation sensors with OR-logic conditions and response when any one of the orientation sensors detects fall condition. The system has a low-cost design to make it available for a wide range of users. The system design takes into consideration the ease of use and comfort wearing for a long time. The system still under testing and a new GPS module will be added in the future work to allow the caregivers to recognize not only the fall accident but also the accurate location of the fall victim.

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