Development of a Real-time Supported System for Firefighters in Emergency Cases

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Abstract— **The firefighters can be injured by unintentional falls during the implementation tasks because of the broken in floors, structure elements; gas bombs; liquid boil ejection and toxic gases… in the fire. Therefore, this paper aims to develop a portable and efficient device to monitor the falls by integrating a micro controller, a 3-DOF (Degrees of Freedom) accelerometer sensor, a MQ7 sensor (Semiconductor Sensor for Carbon Monoxide), a GSM/GPRS (Group Special Mobile/General packet radio service) modem, and the corresponding embedded fall detection algorithms. By developing algorithms and the corresponding simulations to monitor the fall event which can distinguish between being fall and the other daily activities (ADLs) such as standing, walking, running, sitting, lying. The signals from accelerometer are sent to the micro controller to monitor and alert the fall events. The cascade posture recognition is proposed to enhance the fall detection accuracy by determining if the posture is a result of a fall. Furthermore, MQ7 sensor is integrated into the proposed system to confirm the fall directly in emergency situations when air supporting device is working in failure. Based on the detection results, if a person falls with faint, an alert message will be sent to their leader via the GSM/GPRS modem. We had carefully investigated the threshold values (to determine the fall events) and the window size(to determine the time frame for analyzing) by MATLAB. After that, we selected the most suitable values for these parameters to achieve the optimal performance when it is working in emergency places.**

Keywords— **Firefighters, Acceleration, Fall detection, Posture recognitions, Threshold investigations.**

I. INTRODUCTION

According to [1] there are 63,350 US firefighter injuries in 2014 with 27,015 occurred in fireground operations and a total of 64 firefighters died on-duty at the same year [4]. In Vietnam, there are thousands of fires burning every year such as: 2357 and 2792 in 2014 and 2015 respectively [2-3], this is an alarm signal to alert about unsafely for firefighters in both US, Vietnam and in over the world because they always are working and facing with a lot of dangers while they still have not enough and suitable supporting systems to protect their lives such as the fall detection systems in order to help them to escape from the dangerous situations. There are several published methods used to detect the fall events in recent year such as: image processing [5], location sensors 6], smart phones and accelerometers [7-8]…but most of the reported publications were only used for the elderly and patients in clean air environments. Furthermore, the algorithms's performance depend directly on each type of fall events and ADLs [9]. Hence, it is not suitable for firefighter's activities in the fire environment conditions.

Based on the above limitations, this paper proposed to develop a real-time, low cost and high accuracy system which is using a 3-DOF accelerometer, MQ7 CO sensor combined with development the algorithms and the corresponding simulation process to monitor the fall events which can be distinguished between fall and ADLs, it's good for the fire environment and firefighters activities. Furthermore, we had used MATLAB to simulate and chose the best size of the window and values of the threshold to improve the accuracy and performance of the system. The system can work well both in clean and fire environments with the first scenario that combined fall detection and posture recognitions and re-checked after 3 seconds to confirm they are faint or not. The second scenario is the output of both fall detection and CO detection modules to confirm they were fell or not, which caused by having air supporting devices broken.

II. SYSTEM DESIGN

A. The 3-DOF accelerometer

The accelerometer is the heart of our proposed system to detect the fall events of firefighter's on-duty. The sensor used in the system was ADXL345 that can sense the acceleration in three dimensions x, y, z axes subtracted by the gravity vector G (G=9.81 m/s^2). Output data are accessible through the I2C (Inter – Integrated Circuit) digital interface. The accelerometer was positioned in the waist so that y-axis must be paralleled with the earth's gravity to have expected reading results of accelerometers approximately in [0, 9.81, 0] m/s^2 with the rate of 10 samples per second. Then, we applied a preprocessing step before taking data into the attribute extraction module to formulate the mean, orientation and standard deviation. The final step was data mining between fall detection and posture recognition and CO detection modules as well in the real-time.

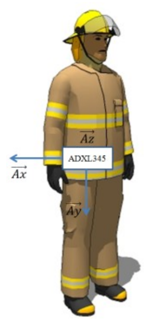

Fig. 1 Position of the 3-DOF accelerometer in waist body

B. Model of fall data processing

Fig. 2 shows the configuration for algorithm verification. The purpose is to investigate the best working conditions for the fall detection device before it would run independently. Firstly, ADXL345 used to get acceleration data in x, y, z – axes and transfer to MCU Pic18F4520 through a standard I2C interface. Then, the MCU will send acquired data to computer through UART (Universal Asynchronous Receiver/Transmitter) communication cable for analyzing algorithms by Matlab. The acceleration data are stored in the buffer of 20 to 40 samples with the sampling rate is 10 Hz.

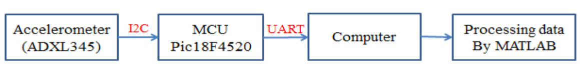

Fig. 2 Fall data processing for fall detection system

C. The fall detection algorithms

The final decision of fall based on the results of either fall detection module and posture recognition or CO detection module (see Fig. 3).

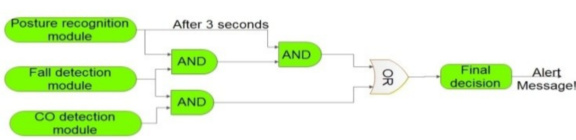

Fig. 3 The summary of fall detection system

Because firefighters are strong, the falling reasons usually come from the external causes such as the broken of floors and constructional elements; gas bombs, toxic gases, liquid boil ejection, etc. Fig. 4 shows the algorithmic architecture embedded in the MCU. The accelerometer will sense acceleration in three dimensions x, y and z, then posture recognition used to confirm the state of firefighters through the combination of three components: posture data base, suitable adjustment mode and acceleration values. Moreover, the proposed system also cares about falling events by the broken in air supporting devices in the high CO environment through the combination of fall detection and CO detection module which mounted inside of the mask.

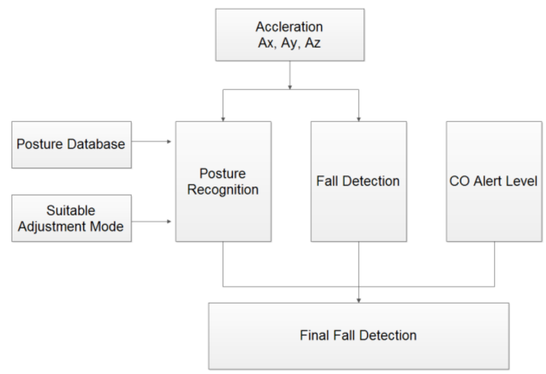

Fig. 4 The proposed algorithms of fall detection

D. Posture Recognition Module

Fig. 5 shows the posture recognition module which will declare whenever people is standing, lying, walking, running, sitting or Null statues (Null state is the state of undefined confirmation). The target of this module that detects the fall events basing on the third threshold. Hence, we do not care about any kinds of postures. In this diagram, A_n is L_2 norm of three accelerations

$$A_n = \sqrt{A_x^2 + A_y^2 + A_z^2}, \tag{1}$$

where n denotes the discrete time. Note that the n^{th} sliding window is formulated as:

$$W_n = [A_n \;\; A_{n-1} \; \dots \; A_{n-19}] \tag{2}$$

After that, the zero cross rate (ZCR) is computed by:

$$ZRC_n = \sum_{i=2}^{20}(A_{n+i} - DC < 0)(A_{n+i-1} - DC > 0) \tag{3}$$

where DC is the DC component of the A_n with ten acceleration samples are averaged and stored in a buffer of the MCU. As can be seen from Fig.5 that when ZCR equals to zero, it means that the firefighters are in steady states.

E. Fall Detection Module

The fall detection module is the difference between two consecutive L_2 acceleration as below:

$$D_n = A_n - A_{n-1} \,. \tag{4}$$

The searching algorithm utilizing D_n is applied to find two positions corresponding to minimum and maximum of A_n, the difference between A_n and A_{n-1} would be compared to another empirical threshold th_4 to determine whether the fall event happens. If th_4 is chosen large, the fall event may be ignored, for small chosen both positive and negative fall events would be declared.

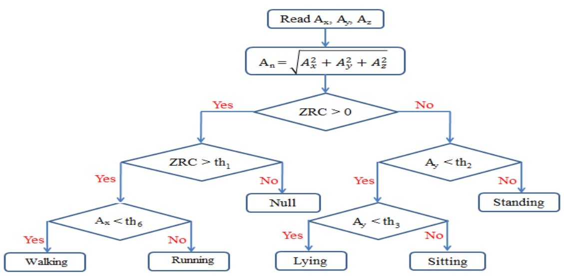

Fig. 5 Flow chart of posture recognition

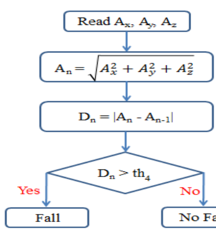

Fig. 6 Fall detection module.

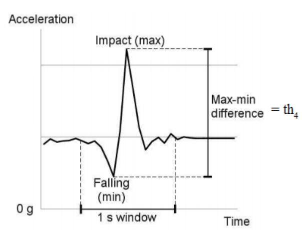

Fig. 7 L_2 acceleration pattern of a fall sample.

F. CO Detection Module

Fig. 8 describes about the process of using MQ7 sensor to detect the fall events by using the threshold value th_5 to distinguish between clean and smoke environments. The reasons in choosing MQ7 sensor that there are a lot toxic gases from the fire burning process [12] such as: CO, CO_2, N_xO, NO_x…it depends on the type of burning materials. Nevertheless, CO named as the "silent killer" is the most dangerous to people's life. MQ7 sensor was mounted inside of the mask to detect CO gas when air supporting devices are working in failure, the value th_5 was chosen based on the process of testing carefully with 10 times between clean and dry wood burning rooms at UFFP.

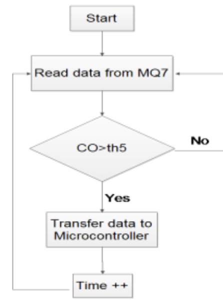

Fig. 8 CO detection algorithm

It can be seen clearly in Fig.9, the values of th_5 between clean and smoke environment in ppm (parts per millions).

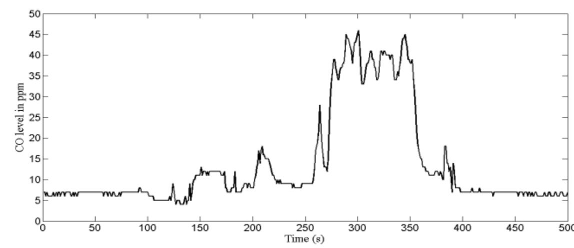

Fig. 9 CO levels between clean and smoke environments.

For the clean environment, this value fluctuated around 7 ppm, and it had increased when we moved MQ7 sensor nearby the main door and th_5 value varied from 33 to 45 ppm when the sensor was located in the room. Based on the real testing process at UFFP that people feel breathless, headache…in the combination of all toxics and CO signs and symptom level, which published in [10], the authors chose $th_5 = 33$ ppm to protect firefighters on-duty.

G. Final Decision

The final decision is based on either output of fall detection combined with posture recognition or CO detection module as shown in Fig. 3. The more details are shown in Fig. 10. When a fall is detected, the first posture recognition is executed to determine if the posture state is Lying or Null. After 3 seconds, the second posture recognition is used to confirm a true fall alarm. The reason for the need of cascade posture recognitions is that after a short time, some firefighters can stand up by themselves. Besides, when a fall is detected in the high CO environment, it means that air supporting devices are working in failure and they need the help of their leader soon to avoid the coming death.

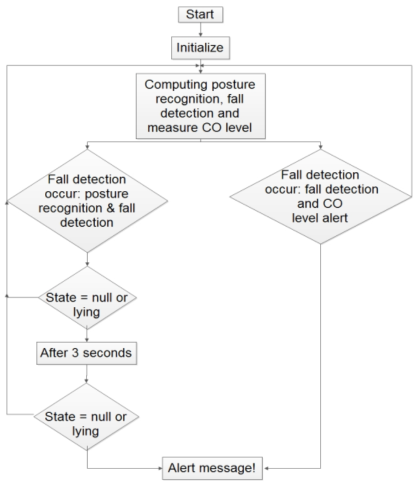

Fig. 10 Fall decision using fall detection combined cascade posture recognitions and CO alert level.

III. Results and discussions

For the experiment testing, we tested on 12 firefighters ages: 18-35, height: 1.68 – 1.75 m, weight: 62-75 kg who were randomly selected from various firefighters in UFFP to get actual data in their life, the volunteers placed the devices on the waist with the most comfortable and CO sensor is located inside the mask. We investigated and tested carefully to find out the suitable window size and threshold values because the accuracy of the system depends on both of them. The window size is 20 samples and threshold $th_4 = 1.4$ m/s^2 are the best values that were chosen. Fig. 11 shows L_2 acceleration, posture recognition, fall detection and final decision with cascade posture recognitions, respectively, to detect exactly fall event at 105th second.

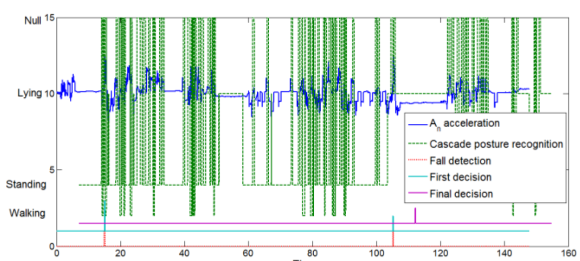

Fig. 11 Fall decision with cascade posture recognitions.

After many experiments, careful analysis and simulation using MATLAB, we have chosen the suitable values for our system that the window size = 20 samples; th_1= 0.7 m/s^2; th_2 = 4.0 m/s^2; th_3 = 1.1 m/s^2; th_4 = 1.4 m/s^2; th_5 = 33 ppm.

IV. Conclusions

In this paper, we had proposed a completed the algorithms, window size and threshold values for fall detection using a 3-DOF accelerometer, a MQ7 sensor, a micro controller, and the corresponding embedded algorithms. In our proposed system, posture recognition used to improve the fall detection; cascade posture recognitions have been introduced to significantly improve the accuracy of the detection system. Furthermore, the paper proposed the suitable threshold value of CO in the fire to protect firefighter lives. The algorithms have firstly been simulated in MATLAB environment and re-programmed in C language to embed for the micro controller. For the future research, we will integrate more sensors and improve the algorithms for online working to save the life of firefighters during the process of implementation task.

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