An Experimental Platform for Fall Detection Using Beacon, Node MCU and MATLAB

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Abstract— **Healthcare wearables have become very powerful and useful devices capable to detect and monitor numerous health parameters and physical conditions. Fall Detection Systems (FDS) are a part of them, with function to detect the falls, mainly in adults. Real-time falls detection may reduce the risk of major problems and enable protective and medical personnel to act immediately. FDS varies in terms of embedded hardware and software (algorithms). Here, we present a system that can be used as an experimental platform to explore the fall detection algorithms based on inertial methods. Battery powered Bluetooth Low Energy (BLE) Beacon with built in accelerometer is used as a sensor device and data transmitter. BLE ESP based gateway receive the data and forward them to MATLAB host, on which experiments are conducted to find the most suitable algorithms. Later, the algorithms are embedded into suitable platforms, which are incorporated into sensor housings, receiver-indicators or home/hospital care systems. The architecture of overall experimentations system as well as preliminary testing results for accelerometer-based algorithms are presented, but without changing the hardware configuration, other algorithms can also be tested.**

Keywords-wearables; fall detection; accelerometer; Beacon; MATLAB; ESP Node

I. INTRODUCTION

Healthcare wearables have become very powerful devices that can detect and monitor numerous health parameters and physical conditions [1]. Although prevention efforts are underway, falls are still a major problem among the elderly population. They often lead to serious injuries, hospitalization, and even death. Not to mention the costs and efforts of the personnel who have to monitor such patients continuously. If a fall happens, then the protective or medical personnel have to react as soon as possible. Therefore, the need to develop a fall detection and alarm systems naturally arose.

A variety of different methods were developed over the last decade to automatically detect falls [2]. These have been based on video-cameras, acoustic sensors, inertial sensors, microwave radars and others. The detection device can be stationary, as cameras and scanners or mobile, most often in the form of a wearable devices, dressed on a body, as watches, bracelets, case on pillows or miniature pocket devices. Nowadays, the wearable sensors became superior because of cost, size, weight, battery powering, ease of use and, most importantly, portability [3]. With high integration and communication bum, the altering and data collection is no longer issue that provided ubiquitous health monitoring, including the remote aspects.

One of the pioneering and to date simplest fall detection systems are based on the inertial technique, where different approaches have been explored by using accelerometer or inertial measurement sensors (accelerometers and gyroscopes). The analysis of accelerometer and/or gyroscope outputs allows for detecting specific events, such as voluntary (e.g., walking, sitting, laying) or involuntary (e.g., fall) activities of daily living, based on statistical, threshold-based or deep learning algorithms. Fussed inertial method is today possible by combining a 3-axis gyroscope and a 3-axis accelerometer as separate chips, or even in the same silicon die [4]. Sometimes, the designers misunderstand the differences between an accelerometer and a gyroscope. Accelerometers measure linear acceleration (specified in mV/g) along one or several axes. A gyroscope measures angular velocity (specified in mV/deg/s). If someone takes accelerometer and imposes a rotation its outputs will not respond to change, as well as vice versa in case of gyroscope in case of linear motion.

In most cases, the fall can be expressed as a combination of linear motions, so the minimum required component for fall detection is an accelerometer. As stated in [5] the algorithms provide a high accuracy. However, one should be reserved when it comes to the accuracy of the fall, because there are completely conflicting conclusions, especially for real-world data, where the accuracy is significantly lower. The occurrence of falls is quite unpredictable.

To explore algorithms, especially for education purposes, the designers and researchers need feasible low-cost platform that meets the following requirements: wearable battery powered sensor, easily attached to body of patient, wireless low-power connection between host and sensor, the host machine that accepts the data and runs powerful mathematical and signal processing software like MATLAB and more. Later, the algorithms are embedded into suitable platforms, which are incorporated into sensor housings (wearables), home/hospital receiver-indicators, home/hospital care systems or represent an integral part of other systems, as it is [6]. This paper presents such system and methodology, which is elaborated through proposed accelerometric algorithms.

II. METHOD

The system consists of hardware and software, Fig. 1. The sensor is in fact battery-powered Beacon, a small radio transmitter that transmits data according to adequate protocol to a compatible reader. It is possible to use any BLE Beacon. In our experiments it is DearBeacon E9, manufactured by MINEW, which is equipped with an accelerometer. The receiver is a MCU node that can work in standalone, gateway or IoT node; as example ESP32 or similar

The principal architecture of the system is shown in Fig. 1.

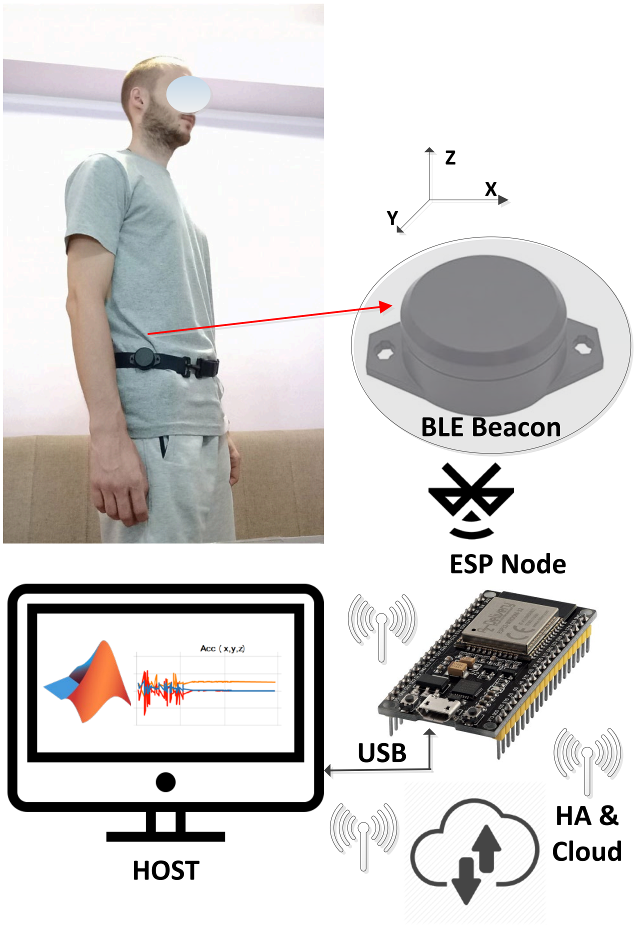

Figure 1. The principal architecture of FDS, based on Beacon, ESP MCU node and Matlab

A. *Fall detection from accelerometric data*

In proposed algorithm the fall is detected from accelerometric by using the decision rules over two parameters: the sum of the slope and mean of the max angle. Accelerometer data is firstly acquired in sets of 50 by 10Hz sampling frequency (5 seconds duration) and then processed.

$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}, \qquad (1)$$

where A_x, A_y, A_z are accelerometer data of three amplitudes in a range (±1 g).

The sum of the slopes in the window W of 50 samples size is calculated as (2):

$$slope_{sum} = \sum_{i=1}^{Wi}(A_{i+1} - A_i);\, if\, A_{i+1} > A_i \qquad (2)$$

and $slope_{max}$ (3):

$$slope_{max} = \max\left(slope_{sum}(W1) \ldots slope_{sum}(Wi)\right) \qquad (3)$$

The decision is taken as:

1. $slope_{max} < 0.1$ – for steady position (no movement)
2. $0.1 \leq slope_{max} \leq 0.6$ – for moving, doing everyday activities
3. $slope_{max} > 0.6$ – for the impacts, indicated a fall, jump or running

Only when the third condition is met, there is a chance that a fall has happened and this condition is later reinforced by analyzing the changes of angle.

Angle changes relative to upright position are observed as

$$\phi_{xr} = \phi_x - \phi_{x0};\ \phi_{yr} = \phi_y - \phi_{y0};\ \phi_{zr} = \phi_z - \phi_{z0}, \qquad (4)$$

where ϕ_{x0}, ϕ_{y0}, ϕ_{z0} are tilt angles in upright position, measured experimentally ϕ_{x0} = -64.2°; ϕ_{y0} = 25.74°; ϕ_{z0} = 0°, while individual tilt angles are calculated as below:

$$\phi_x = \tan^{-1}\left(\frac{A_x}{\sqrt{A_y^2+A_z^2}}\right) \qquad (5)$$

$$\phi_y = \tan^{-1}\left(\frac{A_y}{\sqrt{A_x^2+A_z^2}}\right) \qquad (6)$$

$$\phi_z = \tan^{-1}\left(\frac{A_z}{\sqrt{A_x^2+A_y^2}}\right) \qquad (7)$$

When fall happens at least one of these angles will rise to about 90°, so for simplicity only maximal values of these three angles is observed: $\phi_{max} = \max(\phi_x, \phi_y, \phi_z)$. Next, the average value is calculated around peak position to exclude too short bursts which can't indicate a fall because a person needs some time to get up. A few seconds period of observation is enough for such short frame of 5 seconds refreshment rate, $\phi_{avg} = \mathrm{mean}(\phi_{max}[max_{in}, max_{in}+30])$, max_{in} – index of an angle peak and 30 additional samples which correspond to 3 seconds

The peak can happen to be near the end of 50 samples frame so it is less than 30 samples from peak to the end. To make sure that average value is calculated on sufficient number of samples, two consecutive frames are joined to make 100 samples. Thus, when a peak is positioned nearer the end of new frame the average value is calculated upon gathering new samples, which consequently makes additional delay of 5 seconds.

From the angle side of view, an average angle change that meets right conditions to indicate a fall is $\phi_{avg} > 75$. When the both axis and angle conditions are met, we can conclude that there was a fall:

$$\begin{cases} slope_{max} > 0.6 \\ \phi avg > 75 \end{cases} \tag{8}$$

III. EXPERIMENT AND RESULTS

We have tested the proposed methodology in real conditions. For this purpose, MATLAB GUI has been designed that communicates with ESP Node by virtual RS232 over USB. ESP Node scans the presence of nearby Beacons that is indicated by GUI, P1 presents Beacon (patient) 1 etc. and forwards data to MATLAB code. Figure 1 to Figure 7 present different states of the observed person's activity. Red graph background indicates that the fall condition is met (max slope and average phi graphs). It is illustrated how "Jumping", especially several consecutive jumps can be understood as a fall from slope aspect of view, that is logical.

A case of a real fall is shown in Figure 7 where both slope and phi variables surpassed the conditional values, and alarm for patient 1 is turned on.

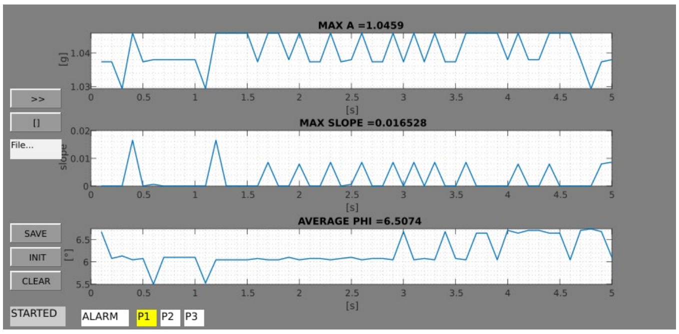

Figure 2. The state of "CALM"

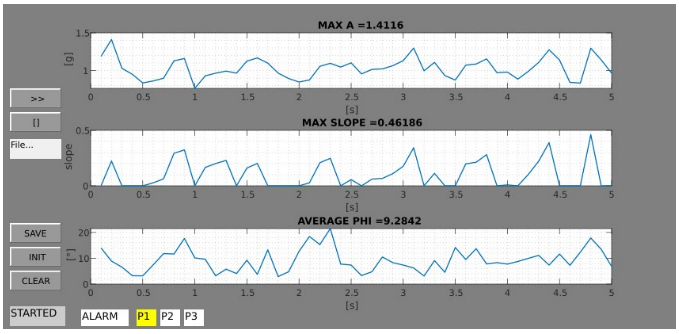

Figure 3. The state of "MOVING"

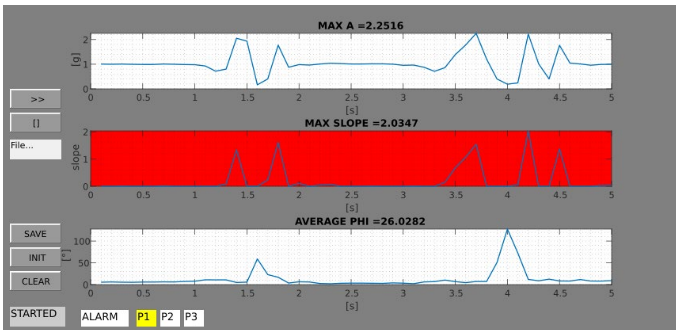

Figure 4. The state of "JUMPING". Several consecutive jumps

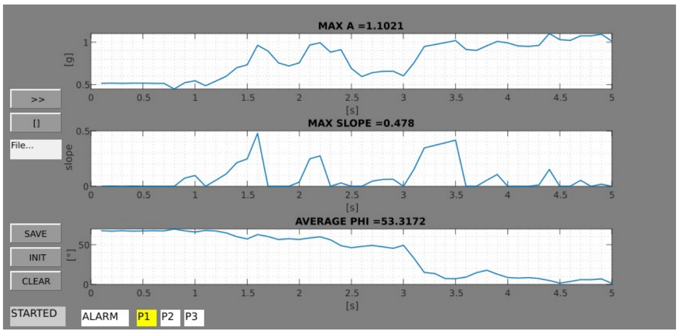

Figure 5. The state of "LAYING DOWN"

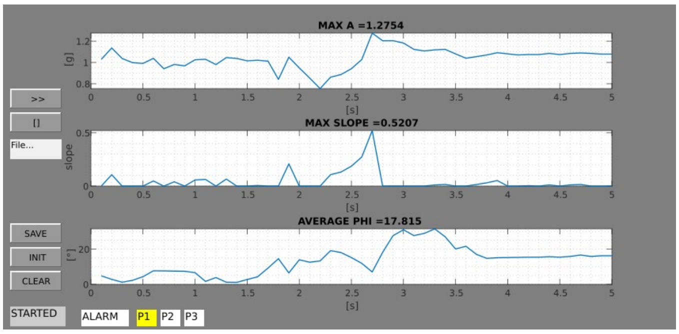

Figure 6. The state of "SITING". Several consecutive jumps

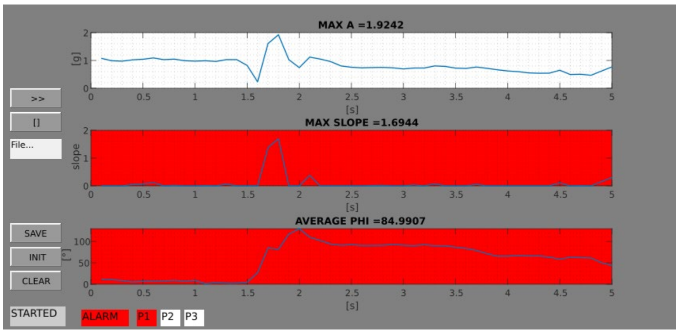

Figure 7. The state of "FALLING DOWN"

TABLE I. FALL DETECTION ACCURACY FOR DIFFERENT STATES (ACTIVITIES)

State/ Action	Correct detection rate (fall or not fall) in %			
	max slope > 0.6 avgphi > 75	max slope > 0.5 avgphi > 75	max slope > 0.6 avgphi > 70	max slope > 0.5 avgphi > 70
Fall	64.14	66.76	76.67	79.3
Moving	100	100	100	100
Laying down/standing up	98.04	94.12	96.48	91.77
Standing or sitting steadily	100	100	100	100
Sitting down/standing up	100	100	100	100
Jumping	99.17	99.17	99.17	99.17

Statistical testing has been performed over the sets of the data that contains different scenario from different persons, Table I. As seen, the fall accuracy is about 64% for real-world data. Other cases produce very low false positives.

Conclusions

This paper presents the experimental methodology for developing and testing algorithms for fall detection. It is low cost and feasible for any laboratory or designer group (company). We showed an example of employing the methodology on proposed accelerometer-based algorithms. The experiments showed that fall detection is still not easy task in case of using only one type of data (accelerometric). Obtained detection accuracy on real-world data is about 67%. Detection of other states has very good accuracy. The experiments on other algorithms, such as the neural networks, etc. are ongoing.

Acknowledgment

Some of the results published in this paper are funded through the PAE Experiment of Project “Self-sustained customized cyberphysical system experiments for capacity building among European stakeholders (SMART4ALL)”, H2020, Grant Agreement No. 872614. We are thankful for support.

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