Wearable Computing Device For Fall Detection In Elderly With Alert Notification

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Abstract- *One of the most common and feared problems in the ageing population is a fall. A fall can cause not only fractures and injuries but also a loss of independence and in the worst case death. With the above mentioned problem, this paper proposes a sensor-based technique combined with image inputs to avoid the misclassification of the results. The proposed method is implemented with the help of an inertia measuring unit and heart rate monitoring unit as a wearable device using the internet of things technology. Data is filtered and pre-processed to extract features to from a data-set for classifying the results using the decision tree model. Thus, this system can be used to not only track the daily activities of the elderly and detect falls by the use of sensors and cameras but also notify the hospitals and caregivers if a fall does take place.*

Keywords- Fall Detection System; Elderly; Internet of Things; Wrist-worn Computing Device; Alert System

I. INTRODUCTION

Compared to all other age groups, the population aged 65 and over is on the rise worldwide. By the year 2050, the population of the elderly is expected to reach about 2 billion. With age, the human body tends to become more fragile and prone to injuries due to the degradation of their physical function. The health risk associated with geriatric care has thus become a major problem of interest with many finding and researching ways to prolong these time-honoured individuals. Among the many age-induced risks, a fall can be quite common and sometimes fatal in the elderly population if not administered immediate medical assistance.

The injuries caused by a fall can be expensive in terms of health-care services and can also include hidden costs to the patient such as loss of independence, depression and even mortality. To overcome such consequences, a low cost real-time monitoring system can serve the purpose of detecting an unfortunate fall and receiving the necessary response in return. With the advancements in the internet of things (IoT)[1], wearable technology has become affordable and easily accessible. The various advantages of a wearable health monitoring device coupled with lack of technical knowledge that the elderly population possesses forms an effective mechanism of keeping a track on the patient. Not only are these devices easy to use but can also be very low maintenance.

The ever increasing usage of smartphones and super-fast wireless connection has boosted to growth of IoT development especially in the healthcare sector. The contributions of IoT are greatly influenced by the introduction of various smart objects used to create health services for solving the problems faced by the present world. Through this paper, we propose an alert message notification along with an image captured by a camera after a fall has been detected in order to help the caregiver decide whether immediate action must be taken or it is just a false alarm.

II. RELATED WORK

A definition of fall detection system (FDS) by the authors in paper [2], states that it is *"an assisting device that is capable of sensing, processing and communicating alarm data in the event of a fall under real-life conditions effectively"*. The approaches to implementing a FDS which can be broadly classified as: Image-based analytical systems, Wearable sensor-based systems and Ambient-based sensing systems. However, this paper focuses mainly on wearable threshold-based automatic fall detecting mechanism primarily employed in geriatrics as falls are more frequent in the elderly.

Wearable FDS [3]usually use accelerometers, which are devices sensitive to vibrations and movement. Only accelerometer systems however do not provide accurate results in all conditions. Hence, multiple sensors have been fused and experimented to increase the system accuracy. For instance, Shahiduzzaman et al. [4] combines an accelerator with a heart rate variability (HRV) sensor in a threshold-based FDS. Both the sensors are analyzed for abnormalities in their produced signals. Variations in the heart rate of the patient were used to indicate the distress experienced at thetime of a fall. If both the signals under analysis were to cross a particular set threshold then the occurrence of a fall was reported to have taken place. This study showed about 98% accuracy in distinguishing a fall from activities of daily living (ADL) [2], [3], [5] -[6]. Another example in paper [7] makes use of a barometer and 3-axis accelerometer to classify falls based on a trained support vector machine (SVM) [3] technique. It focuses on reducing excessive barometric noise by filtering the signals before extracting 3 features namely, pressure-shift, middle slope and post fall slope which are fed to the SVM for training and testing the Machine Learning (ML) model.

In [5], the authors state that the thresholds chosen and positioning of micro-electrometrical system (MEMS) sensors impact the accuracy of fall detection. Experiments were conducted by placing sensors on the shoulder, waist, and foot regions of the patients. Based on the adjustments made to both the thresholds and placement of the sensors for improving the system performance, a series of observations were made. Sensor placement on the waist resulted in lesser false positives than that on the shoulder and foot. Similarly, Ozcan et al. in [8] used a front facing camera which was bound to the belt of the subject to compare the indoor and outdoor performance of the proposed fall detection algorithm. With this being said, sensing devices that are worn around the waist can cause discomfort to many individuals. Hence, for our system we propose a wrist worn sensing device for fall detection as the wrist is the closest area to the waist and is ideal because most people are accustomed to wearing a watch thereby eliminating the discomfort factor.

According to the article [9], Cleep has a 150 degree 13mp camera embedded to a wearable device worn around the wrist used to capture photos and videos without the requirement of a phone. The authors in paper [10], describes about a similar device which uses an accelerometer and camera to recognize and record the ADLs of the user. Based on this concept of wrist-worn camera device, we intend to use the image captured by a camera after a fall has been detected to serve as decisive evidence in determining whether immediate response by caregivers is required as compared to the buzzer method proposed in [6]. Kukharenko et al. in [11]performed a comparative study on the available threshold-based algorithms (TBA) for fall detection using devices worn on the wrist of an individual. The described approach achieved 66% accuracy and analysis of ADLs was also conducted. Although the system can identify most falling conditions, it fails in detecting false alarms. Therefore, the accuracy of threshold based methods for FDSs are not ideal and must simultaneously utilize ML based algorithms to improve the efficiency of performance.

III. THE PROPOSED SYSTEM

The proposed system is an implementation of wearable computing under the internet of things domain. In general, the fall detection system consists of the following two main components:

A. Wrist-worn computing device
B. Mobile notification system

Figure 1 depicts the system design of our fall detection system. An integration of the above mentioned two components is intended in creating a monitoring system for elderly patients and notifying mechanism to alert the caretakers when a fall happens. Abnormal health conditions such as sudden changes in heart rate will trigger the system to automatically send notifications through a mobile application to the appropriate people.Taking in account the two primary users of this proposed system, namely, the elderly population and their respective caregivers, the system acts as a connecting link between the two and thereby, serves as a mediator between the two remotely located end-users.

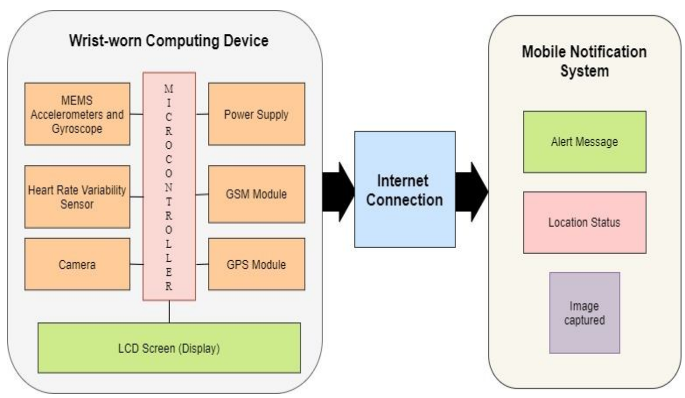

Figure 1: Wrist-worn Fall Detection System Design

A. *Wrist-worn Computing Device*

The elderly monitoring device is a non-intrusive device that must be worn around the wrist of the person and is equipped with the following components:

- Microcontroller: A microcontroller such as ArduinoUNO (commonly used open-source IoT platform) with Arduino development software[6].
- Inertia Measuring Unit: The MPU-6050 device which combines a 3-axis gyroscope and a 3-axis accelerometer on a single unit and supports precise position tracking [6]-[1].
- ECG Monitoring Unit: Electro-cardiogram (ECG) [4], [12]biosensors such as AD8232 Heart Rate

Monitor are used for monitoring the variability in heart rate and to obtain a clear signal from the PR and QT intervals easily.

- Camera: ESP32-CAM is a small-size camera module with reliable wireless connection that can be mounted on the device to capture an image after a fall has been detected.
- Power Supply: The power supply module uses a 5000mAH power bank which can last up to 1 day and also has rechargeable batteries [6].
- LCD Screen: a liquid crystal display (LCD) screen attached to the device updates the individual when the battery is low, increased heart rate and other conditions specified.
- GSM GPRS Module: The GSM GPRS module is actually responsible for wireless connection with the GSM network used for sending alert notifications in the form of a text message along with a picture captured by the camera to the mobile phone of the registered caretakers.
- GPS Module: A GPS module is a three-axis sensor used in spatial navigation that can determine location, altitude, and speed at any time and especially used for tracking purposes.

All the hardware described above are compatible with each other and together the entire arrangement can track the everyday activities of the wearer for self-monitoring of health as well as enabling the care-givers to keep an eye on them through an alert system connected to mobile phone.

B. *Mobile Notification System*

After a fall is detected [6], notifying the appropriate care-givers is also of importance. The GSM GPRS module sends an alert notification in the form a text message along with the current location and a picture captured by the camera to the mobile phone of the registered caretaker. GSM or Global System for Mobile Communication is a wireless communication standard for mobile telephone systems. GPRS or General Packet Radio Service is an extension of the GSM Network. With the integration of GPRS, a packet – switching based data service, in to the GSM Network, the scene of data services has changes. The access time in GPRS is very small and the main advantage is that it allows bursts of data to be transmitted. Remote notification system using GSM module based on context of a fall with real-time response. On receiving the alert notification, the family member can decide on the following 3 courses of action: (i) immediate medical action such as calling an ambulance service to the fallen patient's location, (ii) responding to the alert themselves or (iii) making a call to the patient to check on the situation if they suspect a false alarm. Here, the image sent with the alert helps them in the decision making process thereby avoiding a false positive alert (e.g., unnecessary action from caregivers) and a false negative alert (e.g., lack of attention leading to potentially dangerous situations).. Additionally, in order to recognize this fall notification, the caretaker can customize their smartphone's messaging setting and thus prioritize these alert messages.

C. *Fall Detecting Approach*

In this section, we explain the approach employed for detecting a fall in the elderly using a combination of both the TBA and the ML. Mostly, threshold based algorithm techniques are used for feature extraction and the ML algorithms are used for the classification of events. The primary goal is to beat the TBAs and MLs in recognizing falls and ADLs. Combined fall detection systems use both pre-set sensor data and machine learning models for performing the classification task.

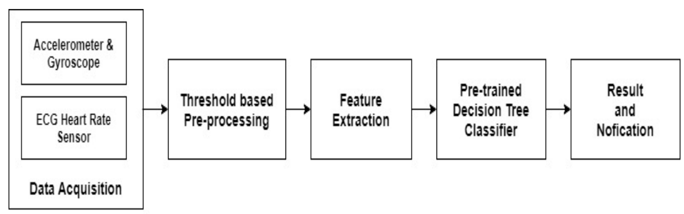

Figure 2: Block Diagram for Fall Detecting Approach

The general block diagram of such a combined system for fall detection based on our proposed method is shown in Figure 2. TBA can be used for only detecting possible fall events. The possible fall events motion data can be then sent to the pre-trained classifier model for final classification. This approach reduces computational and time complexity as the model does not classify every motion event. The model is only used for properly classifying possible fall motion events.

For our approach to fall detection, we chose the window technique as the threshold based algorithm and the decision tree machine learning model for classifying the previously processed data. The data/signals are acquired of from the Inertia Measuring Unit (MPU 6050) and the AD8232 Heart Rate Monitor for detecting variations in ECG [12]. Total magnitude of acceleration including 3 axes is given by,

$$Total\ Acc = \sqrt{(Ax^2 + Ay^2 + Az^2)}$$

Data pre-processing using second order TBA Butter-worth filter with pass band of 0.5 to10Hz as explained in algorithm 2 step-2 of paper [4]. Following this phase, a windowing technique [11] is applied for feature extraction on the real-time data obtained. Windowing is a way to divide the data into a set of consecutive and partially overlapping windows. The time domain features extracted with the use of this method are resultant angle change, maximum resultant angular acceleration, and fluctuation frequency. These fall event detecting features are fed as input to a ML classifier.

Decision tree (DT) algorithm [12] can then be used to classify each window as a fall or a non-fall event. The classifier must be trained in advance with a dataset of the selected features.In DT, the classifications are done based on a tree structure where each node is a variable and its parameters have the evaluation. To evaluate the performance of the classifier and to analyse the correct and incorrect predictions made visually we use the confusion matrix plots. Confusion matrices are generated by varying the threshold values and testing the algorithm's success in detecting and distinguishing fall events from ADL. For every combination of thresholds the appropriate numbers in the confusion matrix were updated:

- the number of true positive events (TP) – fall happened, algorithm detected fall
- the number of false negative events (FP) – no fall happened, algorithm detected a fall
- the number of true negative events (TN) – no fall happened, algorithms did not detect a fall
- the number of false negative events (FN) – fall happened, algorithm did not detect a fall

The results were used to calculate three performance metrics as follows,

$$accuracy = TP + TN/(TP + TN + FP + FN)$$

$$precision = TP/(TP + FP)$$

And

$$recall = TP/(TP + FN)$$

Precision provides information about the proportion of positive fall identifications that are actually falls and recall the proportion of falls that were identified correctly. Unfortunately, these parameters work in different directions, meaning that improving precision typically reduces recall and vice versa. The DT model is evaluated on the sensor data. Finally, in the event of fall detection by the classifier-output, the device must automatically activate the camera and track the GPS location. This information is then transmitted to the concerned family members.

IV. RESULTS AND DISCUSSIONS

From our analysis, we observe that the windowing technique was able to extract the target features in an orderly fashion from the data produced by the sensors attached to the monitoring device. Decision tree classification helps to reduce the total number of false negative and false positive results that may arise during training and testing of the model. Decision tree classification evaluates to accuracy 92.3%, precision 95.46% and recall 91.7%. This indicates that the performance of the algorithms is dependent on various factors such as the type and placement of the sensors, the fall pattern, related thresholds if any, the characteristics of the dataset, and possibly the preprocessing that has been applied to it. The alerting mechanism employed plays a key role in assisting the remote caregiver with health information.

We can say that the image captured post-fall serves as a decisive factor to the caregivers of the patient as to whether immediate response is necessary or it is just a false alarm. Only taking the sensor values into consideration, it is possible that a loss of balance or other such situations can raise alert notifications which may send the caregivers into unwanted panic. Yet, a disadvantage of this method is that the orientation of the wrist at fall detection scenarios can also be misleading in some cases where the image taken does not show any sign of distress even in the case of grave danger.

V. CONCLUSION

This paper was prepared to propose and develop an IoT-based elderly monitoring system with the intention of fall detection and notification in the event of a fall. AnECG sensor coupled with an inertial measurement unit forms the main fall detection apparatus implemented as a wearable computing device worn as a band around the wrist. The specificity and sensitivity of TBA in pre-processing the data was found to be 92% and 91% respectively.The system produces an overall accuracy of 92% and a minimum of 7 hours of operation time. In addition, an image coupled alert notifying systemand location tracking [6] were included to warn the concerned family members about the health status of the patient by means of a GSM GPRS module. All-inclusive, the device is easy-to-understand, cost effective and low-maintenance.

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