Design Flow of a Wearable System for Body Posture Assessment and Fall Detection with Android Smartphone

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***Abstract*— In this paper, we present a design flow of a wearable system for posture assessment and fall detection of a mobile individual using an Android smartphone. The proposed design architecture utilizes the smartphone as data gateway and analyzer in order to provide immediate information to the emergency contact person or a medical facility. We present and analyze the necessary components required to observe body orientation and fall detection. The system is designed to be low power, portable, lightweight and has wireless data communication capability. By capitalizing on multiple types of wireless connections available on the Android smartphone, our design captures posture information and transmit this information to emergency contact person as well as to a central location for data analysis by experts and also for data logging. The posture analyzer and the fall detecting system can be an essential component within a broader wireless body sensor network to monitor a mobile individual who needs constant monitoring and immediate medical treatments.**

Keywords—Body Sensor Network, Fall Detection, Android Smartphone, Body Posture Assessment, Wearable System

I. Introduction

Sudden collapse or fall is one of the most leading unexpected death causes among the senior population [1]. Cardiac arrest, impaired vision, medications, lack of physical activity, surgeries and environmental hazards could cause a sudden collapse and lead to a possible fall [2]. Even though it is difficult to predict these sudden collapses or falling down onto the ground, it could be helpful if an alert system notifies his/her emergency contacts promptly when such a sudden change on their current body orientation is detected.

Detecting an individual's fall can be managed in numerous approaches. One of the popular methods is using image processing techniques by observing the difference among the captured images where the detection system identifies the fall of an object or an individual [3] [4]. Another method that can be adopted is by observing floor vibrations and unusual sounds where the system tries to identify the cause by matching the acquired data with pre-collected vibration and sound patterns [5] [6]. However, more reliable fall detection can be achieved using portable and lightweight wearable sensors designed to offer higher accuracy and power-efficiency [7]. Lightweight sensors such as 3-axis accelerometers and gyroscope can be used for fall prediction, alongside with body posture, arm movement and gesture recognitions [8-10].

Emergency contacts can be reached in various methods when an individual's sudden fall is detected. This can be achieved easily and reliably by using a cellular phone. A cellular phone has the ability to call and/or text a message to the desired contact person. Furthermore, the flexibility of requesting for help dramatically increases when the fall detection system incorporates a smartphone. The smartphone could send enriched information to predefined emergency contacts by not only calling or texting messages, but also transmitting diagnostic information to a central location for data analysis by experts and data logging.

In this paper, we formulate and explore a fundamental approach of a user-friendly wearable system including a smartphone that detects unexpected falling of an individual and notifies desired emergency contacts with detailed information using voice calls, text messages and data communication to a central server using the Internet. Utilizing multiple accelerometers, the proposed design can determine body posture and predict and detect fall in real-time. This wearable system allows patients to outreach for immediate assistance with current and comprehensive information such as patient's location using GPS, activity timestamps, body orientation, vital signs leading to fall and after.

II. System Design Flow

As shown in Figure 1, our system design flow consists of three parts: i) user wearable sensing system, ii) smartphone to acquire data, detect fall and relay messages to the emergency contacts, and iii) Internet communication module for transmitting information to medical expert and also data logging at the central server. Accelerometers are highly sought sensors for movement detection and characterization due to their small size, high level of sensitivity and low cost and low power consumption. Furthermore, accelerometers with embedded wireless transceivers can be used to transmit the 3-axis motion to intelligent devices such as smartphone for posture assessment and fall detection. In our system design flow, the smartphone is the concentric device with built-in software application that collects and analyzes accelerometer data in real-time. Also, it acts as a gateway to communicate with the user's emergency contacts and responsible to send

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important user data to a medical central server. Voice calls and text message will be initiated to predefined contacts as soon as an emergency situation has been declared by the smartphone's software application (e.g., detection of a possible fall).

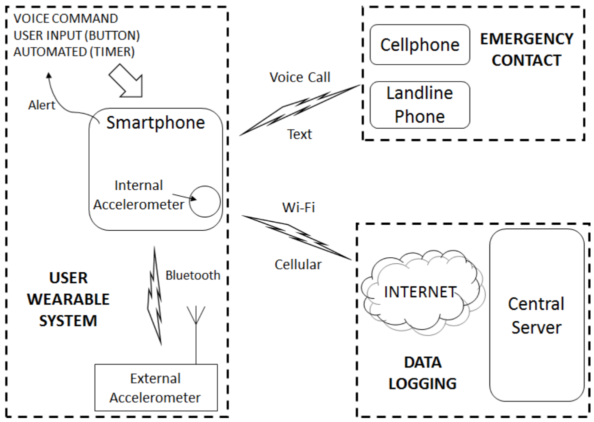

Figure 1. System Design Flow

A. *Wearable Sensors*

Any wearable system needs to be user-friendly, low power, lightweight, and must offer wireless data communication capability to allow mobility. For example a TI eZ430-RF2560 [11] qualifies to be integrated in a wearable unit for monitoring the movement information. This device consists of a MSP430 microcontroller, two embedded sensors including a 3-axis accelerometer and a temperature sensor, couple with a Bluetooth transceiver to transmit sensor data to other smart wireless devices. For our design, the on-board accelerometer and the Bluetooth transceiver can be utilized to collect user movement data on the Android smartphone. As described in Table I, the power consumption of this module is adequate as a wearable mobile sensor device for body sensor network.

TABLE I. TABLE I. POWER CONSUMPTION OF EZ430-RF2560

	Power Consumptions	
	Maximum (Active)	**Minimum (Idle)**
MSP430BT5190 Microcontroller [12]	0.88mA – 1.84mA	1.2µA – 2.1µA
CC2560 Bluetooth Transmitter [13]	39.2mA	40µA
CMA3000-D01 Accelerometer [14]	70µA – 90µA	unknown
TMP106YZC Temperature Sensor [15]	100µA	50µA – 85µA
Total	40.25mA – 41.23mA	91.2µA – 127.1µA
Possible Operational Time	1 day	327 – 456 days

Another example of a smart sensor module that can be utilized in the proposed system is STM STEVAL-MKI063V2 [16] which embeds an ARM-based 32-bit microcontroller, sensors for orientation and movement detections including a gyroscope and an accelerometer, and also Bluetooth transceiver for wireless data communication.

In our current design flow, we developed the Android smartphone application as the data collector, analyzer, and communication gateway using STM STEVAL-MKI063V2. However, the smartphone itself embeds various environmental sensing modules such as accelerometer, RGB light, digital compass, proximity, gyroscope, barometer and more [17] [18]. Also, smartphones are lightweight components which can be easily worn by the user. As shown in our design flow (see Figure 1), the architecture enfolds the smartphone with the internal accelerometer as the body posture and fall detecting sensor module. In addition, our system connects to an external accelerometer module via the Bluetooth connection, where the Android application analyzes both accelerometer data for accurate detection results. As shown in Figure 2, the smartphone can be worn on the chest and an external accelerometer on the thigh to monitor the user's body posture in real-time.

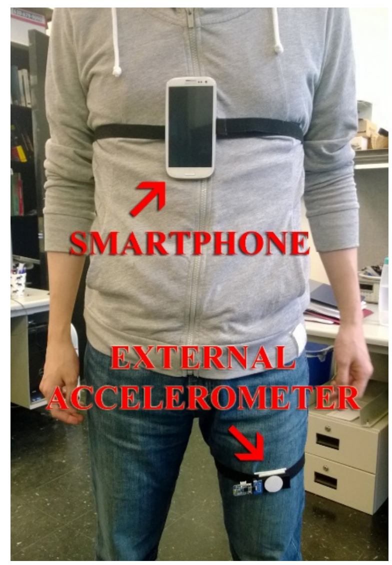

Figure 2. Example of a wearable system configuration with smartphone and external accelerometer

B. *Body Posture Assessments and Fall Detection*

As discussed in the earlier section, there are several approaches for detecting postures and falls of an individual. In our system design, we focus on using accelerometers for such detections. Gestures and postures can be determined by observing the 3-axis accelerometer data. Most of the motion detection techniques using this sensor consist of training its system for better accuracy in characterizing the desired gestures and postures. To achieve accurate results, the system must be trained for numerous iterations of examining the characteristics of the 3-axis acceleration data. Based on the collected data after the training, the system uses the trained data model to examine the incoming data resulting from mobility in real-time. Then, the system interprets the accelerometer data and generates user-friendly information (e.g., natural language) for body posture analysis [8] [9] [19].

Simple fall detection can be achieved by observing the sudden reaction of the 3-axis accelerometer resulting in impulsive signals. In this case, the fall detection system seeks for a rapid data change in the accelerometer data. A rapid change above a predefined threshold is determined as a possible fall. The threshold can be determined similar to methods used for the posture determination [20] [21]. In our study, the system is designed to observe body posture data as well as the rapid data changes to detect a possible fall of an individual. In the event of this rapid change, our system is designed to request for immediate help via voice calls, text messages, and also to transmit alert messages to the central server using the smartphone.

C. Smartphone and Central Server Connectivity

The biggest advantage of using the Android smartphone is in enhancing data mobility, connectivity, and processing capability of our system design. A standard smartphone is equipped with multiple wireless adapters including a Bluetooth transceiver, Wi-Fi and cellular chips for Internet access. Also, it has the capability of a standard cellphone, which are voice calls and texts. As mentioned earlier, the smartphone entails many different sensors that can be useful to determine current condition of the surroundings. In addition to those environmental sensors, the smartphone could obtain user's current location by using the built-in GPS module. The GPS data is a combination of longitude and latitude which can be translated into the exact address with the Geocoder [22]. With these options available on the smartphone, not only it enables users to place a call or text for help, but also it can send user's current GPS location in the event of the fall detection. Figure 3 is an example of a text message sent from the Android application to the emergency contact person with the user's current location and last known body orientation.

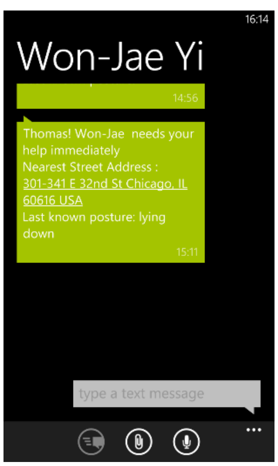

Figure 3. Example of received alert messages

The central server in our design acts as a data storage center for the detected user's posture and fall data in real-time. Through the Internet connection accomplished by the smartphone, the captured data can be stored and displayed on the server. This arrangement enables the remote access of the user data at anywhere through the Internet, as well as keeping history of user data for further and extensive data analysis (e.g. walking/sleeping patterns). As a preliminary approach to this concept, our system displays real-time posture data and fall on the server. Finally, all activity data is recorded with timestamps to keep track of the user's behavior in time as shown in Figure 4.

```
Server up and running... waiting for position

User [Won-Jae Yi] : [siiting down]      at 2013/10/23 15:10:18
User [Won-Jae Yi] : [lying down]        at 2013/10/23 15:10:21
User [Won-Jae Yi] : [sitting down]      at 2013/10/23 15:10:37
User [Won-Jae Yi] : [standing straight] at 2013/10/23 15:10:39
User [Won-Jae Yi] : [sitting down]      at 2013/10/23 15:10:40
User [Won-Jae Yi] : [lying down]        at 2013/10/23 15:10:42
User [Won-Jae Yi] : [sitting down]      at 2013/10/23 15:10:43
User [Won-Jae Yi] : [standing straight] at 2013/10/23 15:10:47
User [Won-Jae Yi] : [sitting down]      at 2013/10/23 15:10:50
User [Won-Jae Yi] : [standing straight] at 2013/10/23 15:10:55
User [Won-Jae Yi] : [lying down]        at 2013/10/23 15:11:01
User [Won-Jae Yi] : [**Possible Fall Detected**
                Nearest Street Address : 301-341 E 32nd St Chicago, IL 60616 USA
                last known posture : lying down] at 2013/10/23 15:11:02
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Figure 4. Example of received user information on the central server from the Android application

III. Wireless Body Sensor Network Architecture

Figure 5 is a general wireless body sensor network (WBSN) architecture where the Personal Communication Node (PCN) collects wearable sensor data through wireless connections. The PCN displays important information to the user after data analysis, and relays to the central medical server for further extensive analysis by experts. Remote diagnosis of a patient can be achieved by establishing WBSN with multiple types of medical sensors. Examples of patient monitoring factors may include blood pressure, electrocardiogram (ECG), body temperature, sweatiness and respiration.

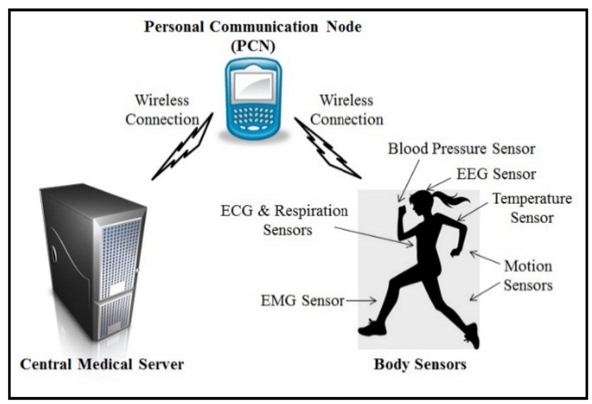

Figure 5. Wireless Body Sensor Network

Single type of body sensor data would not provide sufficient information for diagnosing symptoms accurately. For precise remote patient diagnosis, the system could provide accurate and enhanced remote patient monitoring environment by coupling multiple sensor data with intelligent data analysis. For example, a sudden fall may be detected but the alert message receiver may not be aware of the cause of the fall or the current status of the collapsed person. For example, combination of ECG, blood pressure and respiration data will help the medical expert to determine the cause as a cardiac arrest. Also, the cause for a fall can be further confirmed by analyzing the patient's history stored in the central server. By this arrangement, precise and immediate treatments can be achieved and this can increase the chance of the patient's survival.

IV. CONCLUSION

We have introduced a fundamental design flow of a wearable system for body posture assessment and fall detection. Our design incorporates multiple accelerometers to determine user's current body orientation and to detect the cause of the fall. Accelerometers are used which are lightweight, power-efficient, and have embedded wireless data transmission capabilities. Our Android application encompasses external accelerometer data using the Bluetooth connection, and internal accelerometer data obtained directly from the smartphone. In addition, our system design implements fall alert mechanism whenever an individual's orientation is caused by the event of fall, as well as the known body posture data prior to the fall. Utilizing the Android smartphone, the assessed body posture data along with other medical data captured by body sensors are transmitted to a central server for data logging in real-time. Furthermore, in case of a possible fall, notifying emergency contact person or facility is automatically enabled via voice calls, and texting message with the exact location of the user. Our system design flow can be extended to the wireless body sensor network where more medical body sensors can be employed to provide conclusive patient diagnosis and treatment. This system is also valuable for individuals who are exposed to dangerous environment who needs constant monitoring, including outdoor activities and extreme working conditions.

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