Energy-Efficient IoT-Enabled Fall Detection System with Messenger-Based Notification

Igor Tcarenko[1(✉)], Tuan Nguyen Gia[1], Amir M. Rahmani[1], Tomi Westerlund[1], Pasi Liljeberg[1], and Hannu Tenhunen[1,2]

[1] Department of Information Technology, University of Turku, Turku, Finland
{igotsa,tunggi,amirah,tovewe,pakrli}@utu.fi
[2] Department of Industrial and Medical Electronics, KTH Royal Institute of Technology, Stockholm, Sweden
hannu@imit.kth.se

Abstract. Falls might cause serious traumas especially among elderly people. To deliver timely medical aid, fall detection systems should be able to notify appropriately personnel immediately, when fall occurs. However, as in any system, notification mechanism affects overall energy consumption. Considering that energy efficiency affects reliability, as it influences runtime of the system, notification mechanism should be energy aware. We propose an IoT-enabled fall detection system with a messenger-based notification method, which allows to obtain energy efficient solution, decrease development time and allow to reuse facilities of a popular messaging platform.

Keywords: Internet of Things · Messenger · Fall detection · Fog computing · Energy efficiency · Real-time systems

1 Introduction

Falling is a treacherous issue for elderly. It might cause serious injuries such as bone fractures or traumatic brain damages caused by head traumas for instance [1,2]. More than one third of senior people, whose age is above 65, experiences a fall each year [3]. However, only in less than half of the cases the professional aid is delivered timely. Unattended cases might very likely lead to injuries worsening, which later complicates medical treatment. Fear of falling itself, especially if the aid is not immediate, results in decreased confidence [4], which declines physical activity, lessens social contacts, and eventually leads to depression [5,6]. Thus, there exists an apparent demand for systems which are capable of detecting falls and notifying appropriate personnel.

Internet of Things (IoT), whose application area has been rapidly expanding, provides efficient means for solving variety of problems. In principle, an IoT architecture comprises edge sensor nodes for collecting data, a fog layer [7] for data pre-processing and local decision making as well as a cloud layer for data analysis and storage. All these make IoT a convenient leverage to solve a wide range of

P. Perego et al. (Eds.): MobiHealth 2016, LNICST 192, pp. 19–26, 2017.
DOI: 10.1007/978-3-319-58877-3_3

health-care related problems [8,9] and offer means for monitoring and predicting patients' condition autonomously and remotely. Combined with miniaturized wearable devices that collect patient's health- and activity-related parameters, an IoT-based solution helps to preserve patients' independent lifestyle. Offering several valuable features, wearable's battery-operated nature is one of its main barrier affecting the battery operation time which can result in a limited overall reliability. Reliability is of paramount importance in e-health applications; therefore, we utilise the fog layer that resides in a gateway in our IoT-based fall detection system. Stationary nature of the gateway implies unconstrained power supply, and thus the computational load can be redistributed among the fog and the wearable devices optimizing energy efficiency of the latter.

Notification mechanism is vital for IoT systems such as fall detector. Often an optimal and most promising solution appears as a combination of technologies. As messengers (with over 1 billion monthly active users [10]) are believed to be the next revolutionary communication media after the social networks era, the exploitation of their facilities can reduce the cost of IoT solutions and ease their integration into society.

In this paper, taking advantage of the IoT fog layer, we first built an energy efficient fall detection system. We then amalgamate and consolidate the concepts of IoT and evolutionary mobile messaging to present a messenger-based notification mechanism for our IoT-based fall detection system in order to reduce the implementation cost and enhance wide spread use of the system.

The remainder of the paper is organized as follows. In Sect. 2, we discuss related work and draw the motivation of the work. In Sect. 3, we present the system architecture, after which the system implementation is described in Sect. 4. Section 5 presents experimental results, and finally we conclude in Sect. 6.

2 Related Work and Motivation

Existing approaches for developing fall detection systems can be conventionally categorized into camera-, accelerometer-, gyroscope-based and hybrid solutions. In [11,12], hybrid (Kinect depth camera and accelerometer) and accelerometer-based systems are presented with reported accuracies of 87.29% and 95.71%, respectively. In [13], authors proposed a solution, built on a smartphone utilizing accelerometer measurements with the accuracy of over 93%. In these works, accuracy is in the main focus, leaving energy consumption a secondary role. However, as mentioned, power efficiency is an important component of overall reliability of the solution, and therefore it should be primarily considered in designing the system. Considering all the upsides of the mentioned solutions, such as utilization of widespread platforms and sophisticated analysis algorithms, we, however, uphold the view that the system architecture should stay simple though providing sufficient degree of accuracy. In other words, the solution should avoid unnecessary components which are power hungry. Hence, our approach has an accelerometer-based wearable at its core, because as shown, it can provide sufficient degree of accuracy. Operating in the scope of IoT, in particular in conjunction with the fog layer computing unit, the wearable device can be computationally offloaded, leaving to a sensor node a function of transmitting the measured data.

System's capability to notify appropriate personnel about a fall is essential. Pervasive nature of mobile networks provides a convenient leverage to implement a notification mechanism. A GPRS module, attached to a wearable, represents a viable fall detection system with a pervasive notification method [14]. However, as any part of a system, a notification mechanism affects overall energy efficiency and, therefore, should be considered.

To build energy efficient, yet ubiquitous notification mechanism, we propose to use messengers' bots [15]. Bots approach is an emerging trend in instant messaging technologies. Such bots are basically software-operated messenger users that can resign in a remote or a local network server. Thus, the bots provide an opportunity to leverage messenger's facilities, such as servers and client side applications, for building distributed systems.

Putting all together, the rationale behind this work is to build a reliable and energy efficient fall detection system with a messenger-based notification mechanism, capable of working autonomously for a long period of time.

3 System Architecture

The overall system architecture is shown in Fig. 1. It consists of a wearable device working as a sensor node at the edge layer, a smart gateway with the developed messenger bot at a fog layer, and a messenger server located in a cloud (in our system, we use Telegram Messenger [16]). A fall signal, which indicates that the fall has occurred, is sent to the server from the bot. After receiving the fall notification, the messenger server sends a push notification to the Telegram Messenger client application.

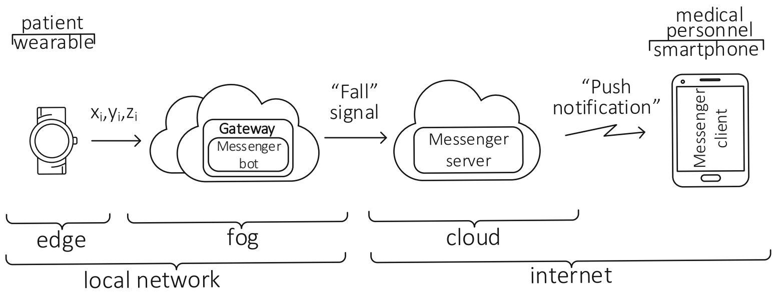

Fig. 1. The system consists of the wearable device, smart gateway with the messenger bot, and messenger server in a cloud. Push notification, triggered by an active fall signal, is sent to a remote smartphone.

Among the fall detection acceleration-based algorithms [14,17–20], we exploit the one which relies on the prototypical acceleration curve of a forward

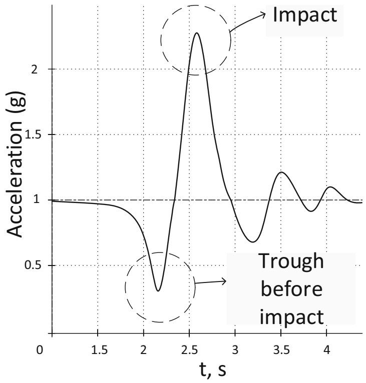

Fig. 2. Prototypical acceleration curve of a forward fall. The pit depicts the falling phase, whereas the peak reflects the impact from hitting the surface.

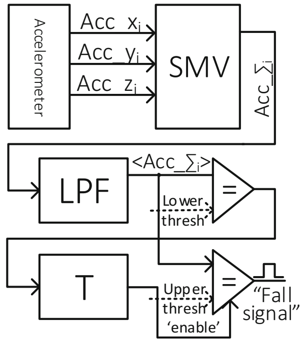

Fig. 3. The block diagram of the algorithm. The algorithm filters the input raw data and searches for the pit and peak.

real-world fall, depicted in Fig. 2. The block diagram of the algorithm includes the calculation of the signal magnitude vector (as a square root of sum of squares of accelerations along X,Y,Z axis), low pass filtering and comparing the result with the lower and higher thresholds in order to draw the final decision (Fig. 3). Hence, the wearable's accelerometer provides acceleration measurements (along three orthogonal axis X,Y,Z) that are sent to the gateway and processed by the aforementioned algorithm (Fig. 2) to draw the final decision about a the occurrence of a fall.

4 Implementation

The implementation of the system is divided into two parts, the sensor node and the fog computing unit, described in the following subsections.

4.1 Sensor Node

The sensor node is responsible for acquiring data from the accelerometer and transmitting it to the gateway in the fog layer. The node consists of three components: a microcontroller, an accelerometer, and a Bluetooth module. For our experiment, we use ATMega328 (microcontroller), ADXL345 (accelerometer), BLE Micro (bluetooth interface). The implemented node is shown in Fig. 4.

The core component is ADXL345 [21]. It is a 3-axis high resolution accelerometer with I2C and SPI communication interface. This chip features an ultra-low power consumption mode, providing measurements at a rate of 200 Hz or 400 Hz, while current consumption is only 90 µA.

ATMega328 (8 MHz), embedded into a tiny (diameter of 50 mm) LilyPad development board, serves as a node's processing unit [22]. It is a low power 8-bit AVR microcontroller. Operating at a speed of 1 MHz, the microcontroller consumes as little as 0.2 mA. The microcontroller has USART and two SPI communication interfaces. The microcontroller receives measurements over SPI interface, whereas the USART is used for communicating with the Bluetooth module.

BLE Micro [23] is an ultra-low power Bluetooth module, which is used for transmitting accelerometer data from the sensor node to the gateway. Operating at 3.3 V, BLE Micro consumes 2 μA in idle mode and around 10 mA when transmitting data at a rate of 1 Mbps (2 Mbps is the maximum data rate). The module's small size (13.0 mm × 18.5 mm × 2.3 mm) makes it suitable for our use case.

4.2 Fog Computing Unit and Client Side Application

The fog layer comprises a computing unit, realized on Raspberry Pi 3 (Fig. 5) with installed Linux-based operating system Raspbian Jessie. The unit plays two roles. First, it serves as a gateway, which connects the lower edge layer with the Telegram server, located in the cloud, by the means of the developed Telegram bot. Second, it processes the received acceleration measurements to detect falls. Communication with the wearable is carried out over the Bluetooth 4.1, whereas the Internet connection is held via Wi-Fi 802.11n.

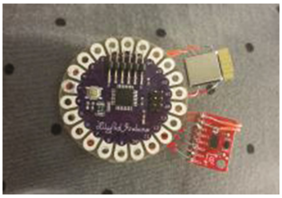

Fig. 4. A wearable sensor node is attached to the patient to detect falls.

Fig. 5. Fog computing unit, with developed bot is realized on Raspberry Pi 3.

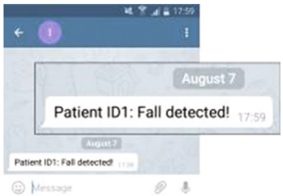

Fig. 6. A client side Telegram messenger has received a notification about the fall.

The unique token, which is used for Fog-Cloud communication, ensures the exclusive identification of the developed bot - this makes the approach scalable. This means that the fog units can be spread in different locations to cover larger area, where each unit will be easily accessed and controlled. Client side application for receiving notifications is a Telegram Messenger android application (Fig. 6).

5 Experimental Results and Demonstration

In order to demonstrate functionality of our fall detection system, the fall detection system was experimented by several volunteers whose heights are between 165–175 cm and weights 60–75 kg. Each volunteer's sensor node is powered by 1100mah Li-Ion battery. The volunteers were monitored while imitating falls at arbitrary times. In the experiment, we estimate energy consumption of the wearable, using the following equation [24]:

$$E = V \times I(w) \times (t(w) - t(o)) + V \times I(o) \times t(o) \quad (1)$$

where E is the total energy consumption (mJ); V is the applied voltage supply; $I(w)$ is an average current consumption while the system is idle (mA); $I(o)$ is an average current consumption when the system is operating (mA); $t(w)$ is waiting time (s) and $t(o)$ is operating time (s).

We compare our approach with an implemented GPRS-based solution, consisting of ATmega328V microcontroller, ADXL345 accelerometer and a SIM900 GPRS module. We use a fall detection algorithm described in Figs. 2 and 3. A notification about a fall is sent via a mobile network as an sms message to a smartphone.

Figure 7a shows energy cost of gathering and transmitting different number of samples for the sensor node, operating in the proposed system. As seen in Fig. 7b, the solution with the GPRS-based notification mechanism requires more energy to realize the same functionality.

Samples	I(mA)	V	E(mJ)
50	29.17	3.3	97.8
100	29.28	3.3	98.1
200	29.39	3.3	98.5

(a) Energy consumptions of a node, operating in the proposed system.

MCU	I(mA)	V	E(mJ)
ATmega328 (16MHz)	104.3	5	521.5
ATmega328 (8MHz)	88.4	3.3	291.72

(b) Energy consumptions of a node with a GPRS-based notification mechanism.

Fig. 7. Experimental results of energy consumption of the proposed solution and the GPRS-based approach.

The results in Fig. 8 demonstrate that the Messenger-based notification mechanism, providing the same coverage as the GPRS-based approach, requires 3 times less energy. In addition, our approach allowed to reuse messenger's client application and servers - this accelerated and simplified development process.

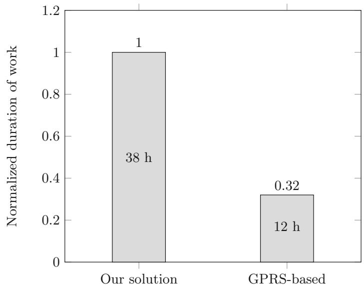

Fig. 8. Comparison of normalized durations of work of the proposed and GPRS-based solutions. Numbers on the bars represent duration of work of the sensor nodes, powered from 1100 mAh battery.

6 Conclusions

Energy efficient fall detection system with a small wearable device at its core was proposed. By leveraging the advantages of the fog computing and messengers' bot platform, the wearable's energy consumption decreased 3 times, compared to the GPRS-based approach. The total operating time of the wearable was 38 h (using a 1100 mAh battery). Combination of IoT and Messengers technologies allowed to address the cost of the solution and its development time. Notification mechanism, which relies on the popular messaging platform, delivers immediate notices to responsible personnel to provide timely aid to the user of the device.

References

1. Sterling, D.A., O'Connor, J.A., Bonadies, J.: Geriatric falls: injury severity is high and disproportionate to mechanism. J. Trauma Acute Care Surg. **50**(1), 116–119 (2001)
2. Stevens, J.A., Corso, P.S., Finkelstein, E.A., Miller, T.R.: The costs of fatal and non-fatal falls among older adults. Inj. Prev. **12**(5), 290–295 (2006)
3. CDC-Centers for Disease control and prevention: Important facts about falls, January 2016. http://www.cdc.gov/homeandrecreationalsafety/falls/adultfalls.html. Accessed Jul 2016
4. Friedman, S.M., Munoz, B., West, S.K., Rubin, G.S., Fried, L.P.: Falls and fear of falling: which comes first? J. Am. Geriatr. Soc. **50**(8), 1329–1335 (2002)
5. Scheffer, A.C., et al.: Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. Age Ageing **37**(1), 19–24 (2008)
6. Igual, R., Medrano, C., Plaza, I.: Challenges, issues and trends in fall detection systems. Biomed. Eng. Online **12**(1), 1 (2013)
7. Bonomi, F., Milito, R., Zhu, J., Addepalli, S.: Fog computing and its role in the internet of things. In: Proceedings of the 1st edition of the MCC Workshop on Mobile Cloud Computing, pp. 13–16. ACM (2012)
8. Gia, T.N., et al.: Fog computing in healthcare internet of things: a case study on ECG feature extraction. In: 2015 IEEE International Conference on Computer and Information Technology (CIT), pp. 356–363. IEEE (2015)

9. Natarajan, K., Prasath, B., Kokila, P.: Smart health care system using internet of things. J. Netw. Commun. Emerg. Technol. (JNCET) **6**(3) (2016). www.jncet.org
10. Statista. Number of monthly active WhatsApp users. http://www.statista.com/statistics/260819/number-of-monthly-active-whatsapp-users/
11. Kepski, M., Kwolek, B.: Embedded system for fall detection using body-worn accelerometer and depth sensor. In: 2015 IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), vol. 2, pp. 755–759. IEEE (2015)
12. Kostopoulos, P., et al.: Increased fall detection accuracy in an accelerometer-based algorithm considering residual movement. In: International Conference on Pattern Recognition Applications and Methods (2015)
13. Casilari, E., Oviedo-Jiménez, M.A.: Automatic fall detection system based on the combined use of a smartphone and a smartwatch. PloS One **10**(11), e0140929 (2015)
14. Tang, A.Y.C., Ong, C.-H., Ahmad, A.: Fall detection sensor system for the elderly. Int. J. Adv. Comput. Res. **5**(19), 176 (2015)
15. Telegram.org. Telegram bot platform. https://telegram.org/blog/bot-revolution
16. Telegram.org. Telegram. https://telegram.org/
17. Li, Y., et al.: Accelerometer-based fall detection sensor system for the elderly. In: 2012 IEEE 2nd International Conference on Cloud Computing and Intelligence Systems, vol. 3, pp. 1216–1220. IEEE (2012)
18. Nguyen, T.T., Cho, M.-C., Lee, T.-S.: Automatic fall detection using wearable biomedical signal measurement terminal. In: 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 5203–5206. IEEE (2009)
19. Li, Q., et al.: Accurate, fast fall detection using gyroscopes and accelerometer-derived posture information. In: 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks, pp. 138–143. IEEE (2009)
20. Odunmbaku, A., et al.: Elderly monitoring system with sleep and fall detector. In: International Conference on IoT Technologies for HealthCare (2015)
21. Analog Devices: Adxl345-digital accelerometer, January 2016. http://www.analog.com/media/en/technical-documentation/data-sheets/ADXL345.pdf. Accessed Jul 2016
22. Leah and SparkFun: Lilypad arduino mainboard, January 2016. https://www.arduino.cc/en/Main/ArduinoBoardLilyPad. Accessed Jul 2016
23. Seeed Studio: Ble micro, January 2016. http://www.seeedstudio.com/wiki/BLE_Micro. Accessed Jul 2016
24. Gia, T.N., et al.: Fog computing in body sensor networks: an energy efficient approach. In: IEEE International Body Sensor Networks Conference (BSN 2015) (2015)