AUTOMATIC FALL DETECTION AND ALERT SYSTEM

A Compact GPS/GSM Enabled Unit based on Accelerometry

Hugo Silva, Filipe Silva, Hugo Gamboa
PLUX – Biosensor Engineering, Av. 5 de Outubro nº 70 – 8º, Lisbon, Portugal
{hsilva, fsilva}@plux.info

Vítor Viegas
EST – IPS, Setúbal, Portugal
vviegas@est.ips.pt

Keywords: Healthcare, Quality of Life, Accelerometry, Biomechanics, Kinematics.

Abstract: Accidental falls are among one of the main causes of death and disability on elderly people. This stands both as a healthcare problem, in the sense that, upon falling, if individuals are not assisted in an early stage severe long term consequences may arise; and as a limitation for the individual's daily life, in the sense that they generally deprive themselves of regular routines as a preventive measure to avoid falling. In this paper we describe a hardware unit conceived to automatically detect fall events, and trigger a set of alert actions which allow the remote detection of the occurrence and facilitate rapid assistance.

1 INTRODUCTION

Population aging is nowadays growing to a worldwide concern. In the U.S., projections for 2000 pointed a 14,3% population share for senior citizens of 65+; projections indicate that this number will grow by 2050 to an impressive 22,6% (U.S. Census Bureau, 2004), disturbing the balance in the population structure.

The leading cause of death by injuries, and one of the main causes of disability in elderly citizens, are accidental falls (CDC, 2006). Statistics show that, in the U.S., more than one third of the senior population with 65+ fall every year with dramatic outcomes (Hausdorff *et al*, 2001; Hornbrook *et al*, 1994). Besides the increase in the number of deaths resulting from involuntary falls (Stevens, 2006), fall-related injuries usually have severe mid- and long-term consequences (Jager *et al*, 2000; Bell *et al*, 2000).

Necessary financial and logistics resources to provide for appropriate nursing services are highly demanding on healthcare systems; in 2000 direct medical costs resulting from fatal falls ascended to $0.2 billion, and $19 billion for the non-fatal case (Stevens *et al.*, 2006). It is estimated that by 2020 the overall direct and indirect fall-related costs will surpass $43 billion (Englander *et al*, 1996).

Furthermore, fall consequences diminish the individual's quality of life, standing in many cases as a long-term limitation to a regular daily life. Fear of falling leads, among others, to mobility reduction and fitness degradation, further potentiating the risk of involuntary falls (British Columbia Ministry of Health Planning Office of the Provincial Health Officer, 2004).

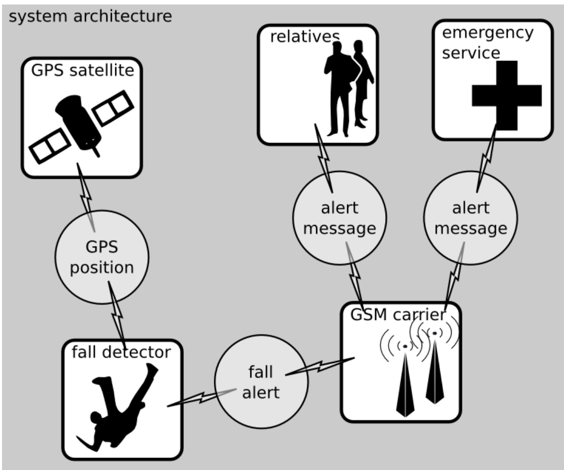

Figure 1: Fall detector system architecture.

This is a trend in most developing countries, and critical issues like the quality of life and healthcare for senior citizens are rapidly arising, thus making way for the development of novel, efficient and cost-effective methods and technologies.

In this paper we present a GPS/GSM enabled portable hardware unit, designed with the purpose of automatically detecting involuntary fall events to alert emergency or nursing teams upon fall detection (Figure 1). The system facilitates rapid assistance allowing remote detection of the occurrence, as well as the GPS coordinates to track the user location.

2 HARDWARE

Recent advances in hardware design and integration provide appropriate conditions for the development of compact, miniaturized systems with a wide application range in real-time signal acquisition and processing (Silva et al, 2005).

For the fall detector hardware unit, three main vectors guided the development process: *(a) automation*; *(b) autonomy*; and *(c) miniaturization*. With a small form factor, the unit was desgined to be worn at waist level, measuring 5.2x5.2x1.6cm, and weighting aproximately 55g.

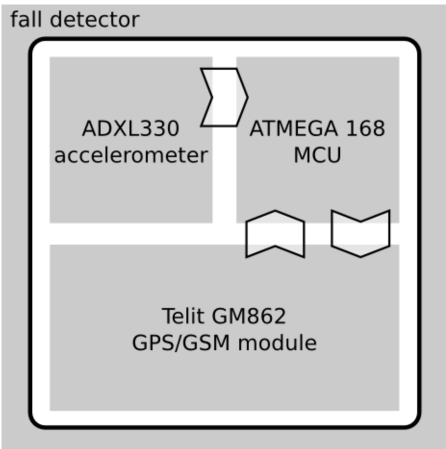

Figure 2: Fall detector block diagram.

Figure 2 depicts the block diagram for the fall detector hardware unit, in which there are three main components which will be detailed next: *(a) accelerometry sensor*; *(b) MCU*; and *(c) GPS/GSM module*.

2.1 Accelerometry Sensor

Fall events can be detected using a number of heuristics; we recur to accelerometry in order to detect sudden changes in magnitude, and angular position.

The fall detector hardware unit integrates one ADXL330 ±3G MEMS® tri-axial accelerometer which measures the acceleration in the cartesian tri-dimensional coordinate space.

To maximize the unit's autonomy, the system is maintained in an idle mode, only being activated if the accelerometer readings exceed a pre-defined magnitude level.

A set of comparators establishes the threshold, and a hardware interrupt is triggered in the MCU whenever the threshold is superseded by one of the axis, switching it to active mode. This works as a pre-filter for the fall detection algorithm discarding standard daily life actions as walking, trunk rotations, among others.

2.2 Microcontroller Unit

An ATMEGA168-20PU MCU is used to command the hardware unit, maintain runtime data, and implement the alert and working logic. It has 16KB program memory, one 16 bit and two 8 bit timers, serial interface, a built-in 6 channel Analog-to-Digital Converter (ADC), and two externally triggered interrupts.

The MCU is kept in idle mode, switching to active mode from time to time as established by the watchdog mode previously described in Section 2.1. Once activated by the accelerometer, the MCU is switched to active mode starting the real-time accelerometer output signal acquisition and processing routine.

If the fall detection software algorithm identifies a fall event, the MCU enters in alert mode, waking up the GPS/GSM module to conduct the procedure described in Section 3.2.

2.3 GPS/GSM Module

GPS/GSM services are assured by a low power, small form factor, Telit GM862 module. It is controlled via AT commands from the MCU through the serial interface, and it has a built-in GPS receiver and a fully functional GSM device.

Two antennas are necessary in order to guarantee the Radio Frequency (RF) signal reception for each function. For this hardware unit we used two low power consumption, small footprint, PCB antennas, of 13.4x13.4x5.5mm and 42x16x1.6mm, for the GPS and GSM components respectively.

2.4 Power

The unit is powered by a Li-Ion rechargeable battery with 3.7V nominal tension, and 2000mAh nominal current. Table 1 presents the mean power consumption analysis for the hardware unit. From Table 1, and taking into account the operating modes of the unit, an estimated battery lifetime of 72h is achievable.

The GPS/GSM module described in Section 2.3 has a built-in battery charger, and charge level indicator. Since we are using a rechargeable battery, the battery status and charger functions from the GM862 are also used. Without introducing additional circuitry we are able to charge the battery on-board, and assess the battery level during the watchdog mode previously described in Section 3.1.

Table 1: Fall detector mean power consumption.

Item	Mode	Consumption (mA)
Accelerometry Sensor	Active	0.32
MCU	Idle	5.20
	Active	9.70
GPS/GSM	Idle	4.00
	GPS Search	60
Antenna	-	13

3 OPERATING MODES

When first connected from a complete power down state, the hardware unit has a cold start time of <60s. The Microcontroller Unit (MCU) starts in active mode and performs the following initialization tasks (Figure 3): *(a)* connect the GPS unit; *(b)* register the GSM in the carrier network; *(c)* search the SIM card memory for the predefined emergency phone number that should be used while in alert mode; *(d)* and store this number in the runtime memory.

During this sequence, a red led is used to indicate that the unit is in start up mode. When the initialization tasks are completed, the MCU puts the GPS/GSM module into sleep mode.

While connected, the hardware unit has two possible operating states: *(a) watchdog mode*; and *(b) alert mode*. The watchdog mode is the state in which the unit is normally working, while the alert mode is the state in which the unit will enter upon detection of a fall event.

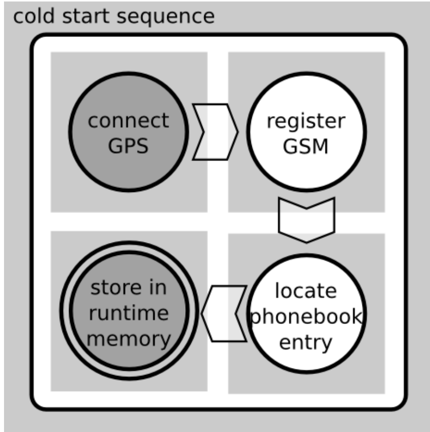

Figure 3: Cold start state diagram.

3.1 Watchdog

This is the mode in which the unit operates until a fall event is detected.

While in watchdog mode, every 4s the MCU wakes up to signal the battery status; the activity indicator led blinks with the colour varying according to the battery charge level: *(a) green*, >50%; *(b) yellow*, =50%; and *(c) red*, <50%.

Every 10m the MCU communicates with the GPS/GSM module in order to update the battery status and to determine the current GPS location of the hardware unit. The last known GPS location is stored in the runtime memory of the MCU.

3.2 Alert

If a potential fall detected by the pre-filter (described ahead in Section 2.1), the MCU is activated entering the alert mode.

In this stage the fall detection software algorithm traces the input signal in order to check if it is a real fall or a false alarm. If a false alarm is detected, the unit goes back into watchdog mode. If it is validated as a real fall, the MCU wakes up the GPS/GSM unit, a text string is formed containing the date, time, alarm notice, and last known GPS position, and sent as a Short Message Service (SMS) text message to the predefined emergency number loaded to the runtime memory during the initialization tasks.

Upon failure in sending the alert SMS, the hardware unit maintains the alert mode. If at first the message is not sent, the process is retried for three times. If the message fails sending in all consecutive tries, the GPS/GSM module is restarted, and the MCU initiates the alert message procedure once more. This process is repeated until the hardware unit is disconnected or until the message is successfully sent.

4 CONCLUSIONS

This paper describes the implementation of an automatic fall detection hardware unit (Brown, 2005). Due to its compact size, it is easily worn, and it does not limit the actions of its bearer.

With the integrated GPS/GSM feature, it allows the remote detection of fall events and indicates the last known GPS location of the unit's bearer, therefore facilitating the rapid intervention of family members, emergency or nursing teams in case of fall (Figure 1).

Most accidental falls occur in contexts in which subjects are often alone and without means of calling for aid upon falling; also, involuntary falls have severe consequences, both in terms of healthcare and quality of life. Portable fall detection units are therefore a useful tool which play a major role, in minimizing the adverse health consequences of falls and in improving the confidence of fall victims so that they do not deprive themselves of their regular activities.

REFERENCES

Bell A., Talbot-Stern J., Hennessy A., 2000. Characteristics and outcomes of older patients presenting to the emergency department after a fall: a retrospective analysis. *Medical Journal of Australia*; 173(4):176–7.

British Columbia Ministry of Health Planning Office of the Provincial Health Officer, 2004. Prevention of falls and injuries among the elderly: A special report from the office of the provincial health officer. (online; accessed 2007 Sep 10). *Available from URL:* http://www.healthservices.gov.bc.ca/pho/special.html

Brown G., 2005. An accelerometer based fall detector: Development, experimentation, and analysis. *University of California, Berkeley, SUPERB Technical Report*.

Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, 2006. Web-based injury statistics query and reporting system (WISQARS) (online; accessed 2007 Sep 10). *Available from URL:* www.cdc.gov/ncipc/wisqars

Englander F, Hodson T., Terregrossa R., 1996. Economic dimensions of slip and fall injuries. *Journal of Forensic Science*; 41(5):733–46.

Hausdorff J., Rios D., Edelber H., 2001. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Archives of Physical Medicine and Rehabilitation* 82(8):1050–6.

Hornbrook M., Stevens V., Wingfield D., Hollis J., Greenlick M., Ory M., 1994. Preventing falls among community-dwelling older persons: results from a randomized trial. *The Gerontologist* 34(1):16–23.

Jager T., Weiss H., Coben J., Pepe P., 2000. Traumatic brain injuries evaluated in U.S. emergency departments, 1992–1994. *Academic Emergency Medicine*; 7(2): 134–40.

Silva H., Gamboa H., Viegas V., and Fred A., 2005. Wireless physiologic data acquisition platform. In *Proceedings of the 2005 Conference on Telecommunications*.

Stevens J., 2006. Fatalities and injuries from falls among older adults — United States, 1993–2003 and 2001–2005. MMWR; 55(45).

Stevens J., Corso P., Finkelstein E., Miller T., 2006. The costs of fatal and nonfatal falls among older adults. *Injury Prevention*; 12:290–5.

U.S. Census Bureau, 2004. U.S. Web-based interim projections by age, sex, race, and hispanic origin. (online; accessed 2007 Sep 10). *Available from URL:* http://www.census.gov/ipc/www/usinterimproj