Design of a smart accelerometric sensor for monitoring of physical risk events

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Abstract —Falls and accidents associated with physical activities are a serious problem in the elderly and people with disabilities. They induce injuries, hospital inputs, and even dead. Their consequences include psychological effects and finally loss of personal autonomy and dependence. Wearable and ubiquitous devices with ability to detect such risk events were proposed time ago, but no falling detector has achieved the acceptance by socio-healthcare providers yet.
This paper presents preliminary results of a pre-industrial research focused to the development of a novel smart monitor able to surpass current industrial barriers. Outcomes suggest the ability of our system to meet both high efficiency and unobtrusive and attractive design.

Keywords: Smart sensors; Signal processing; Movement human monitor; Falling detector; Adaptive impact algorithm.

1. INTRODUCTION

Falls and physical risk situations appear frequently in the elderly and people with several chronic pathologies and disabilities. They induce severe injuries, hospital inputs, and even dead. Moreover, their consequences embrace also psychological effects; fear of falling and reduction on physical activities. This sequence of stages constitutes a positive closed loop feedback that leads to health decline, loss of personal autonomy, and dependency. Many epidemiologic studies have analyzed this problematic [1-3], and their strong implications on the economic burden of healthcare [4-7].

There has been much research to develop strategies that promote the security of people with history and risk of fallings. One relevant line has been the development of wearable and ubiquitous devices with ability to detect in a reliable way such physical situations. These real time falling detectors could perform urgent communications to a telehealthcare center to assure a fast medical assistance.

This approach helps to the fear of falling, and this way the number and severity of falls [3]. Modern systems designed to detect falls use to provide also information regarding the subject physical activity, together with kinematic and postural data.

Several studies show the feasibility of detecting postural states along the estimation of kinetic and metabolic parameters from accelerometric analyses [8-9]. Progress in Micro-Electro-Mechanical Systems (MEMS) has facilitated that wearable inertial sensors have been used to measure body accelerations and try to monitor movements and detect falls. In fact, accelerometric sensors have been researched with this goal since 70's and the efforts have been intensified in the e-health area. Besides this, technical advances in electronics and telecommunications systems design seem support the possibility to develop wearable low-cost motion monitoring and falling detection.

An important problem of falling detection is the definition of falling. Biomechanics of a human fall is very complex, due to the high variability of movement patterns and forces involved in a fall. This manner, the intention to detect falls by rigid analysis of accelerations may be unsuccessful. To avoid this situation as far as possible the existing developments tend to generate a significant percentage of false alarms, which otherwise do not guarantee a real enough sensitivity to alarms (close to 100%). We agree with [10] that it is not a falling but a risk physical activity associated with damage what should be detected by smart detectors. As there are many types of physical risk situations, a distribute architecture that split tasks according their functional objective was defined in [11]. Events were classified as impact-based and non-impact based.

Preliminary studies of our research group pointed to two main problems that impede the adoption of such systems for service providers: high rate of false positives and low discretion [10, 11].

Our group has researched in a new architecture and methodology oriented to the capture of risk physical events, joining concepts from virtual physiological human (VPH) and e-health fields [11]. Preliminary advances presented in [11] have been completed and submitted to an international journal, showing the success of a very light adaptive algorithm, customized to the user and implemented in the smart sensor of our monitor architecture.

This paper and [12] will present an advance of a subsequent line of pre-industrial research. The present paper addresses system functions involved mainly with sensor and processing subsystem. It is a key issue due to the distributed nature of the monitor, which supports the ability to meet a high efficiency together with an unobtrusive and attractive design.

2. ARCHITECTURE AND METHODS

In agreement with [12], the following requirements are needed to accomplish its acceptation:

1. Goodness of detection risk of physical events, including falls. It must combine a very low false positive rate with a very high true positive rate.
2. Small enough to be used 24 hours, regardless of clothing.

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3. High autonomy.

4. Discrete and attractive design. An important factor for acceptance by the user is the discretion. Several studies address this issue like [13].

A first design developed by one of the authors in the framework of his doctoral thesis (PhD), patented [14], and tested afterwards [15], used two ADXL202E (biaxial) accelerometers, a microcontroller PIC16LC66 and the 868 MHz ISM as carrier for the wireless personal area network. That first version followed a line of evolution that took advantage of new advances in electronics. Despite several interesting findings, those previous designs did not fulfill our goals of size and power consumption, which are needed for their industrial deployment.

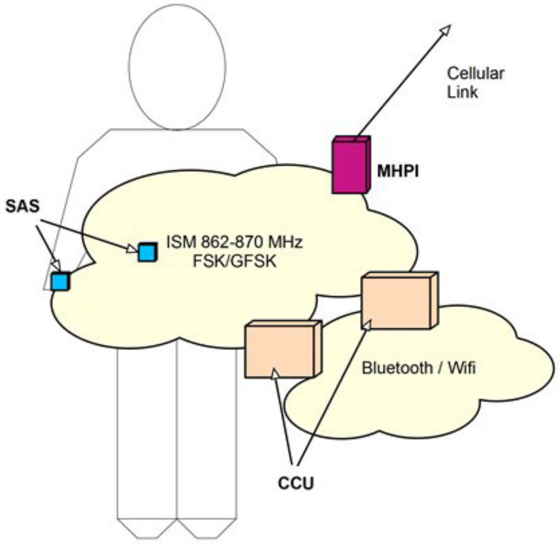

Figure 1. Simplified functional architecture of full system monitor. Two smart sensors are shown.

Current design follows architecture presented at [11], Figure 1 shows wireless personal area network using the 868 MHz ISM band as carrier. SAS detect impacts using energy based algorithm and the MHPI runs a finite-degree biomechanical model to analyze the physical dynamics, both after request of SAS (impact warning) or in a periodic manner. MHPI (Mobile Human Physiological Image) consists of a Smartphone. There have been shown that the division of functional tasks in a distributed manner is an efficient form to achieve our objectives [10, 11].

Smart Accelerometric Sensor (SAS) and Smartphone are linked by a Wireless Personal Area Network (WPAN) in the ISM band using an ultralow power transceiver. When the distance between them is over ~10 m, they are linked via Communications Converter Units (CCU) deployed in home / center. CCUs connect among them by BT technology, and retransmit data in the ISM band. More details concerning this architecture also are explained in [12].

Subsequent sections will present the electronic design of SAS by means of an Orcad schematic model, as well as Matlab/Simulink models to evaluate the influence of the impact detection algorithm on power consumption. This study complements the other presented in [12] and focused to the communication subsystem. Our models use theoretical data of consumption values according to data sheets.

3. RESULTS

3.1 Hardware Architecture

Fig. 2 shows a simplified block diagram of the SAS, with the major electronic subsystems.

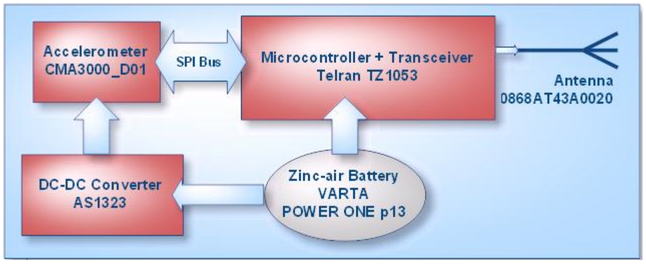

Figure 2. Block diagram of the devices chosen for the SAS.

The internal MEMS and microelectronic devices were selected assuring a minimum size and lower power for the required functional specification. They are listed below:

- Accelerometer: we selected the triaxial accelerometer from VTI Technologies CMA3000_D01, with a configurable range of ± 2g and ± 8g[2]. It´s responsible for taking measures acceleration. Features: ultra low current consumption, configurable sample rate (10/40/100/400 Hz), three operation modes (Measurement Mode / Motion Detection Mode / Free-Fall Mode), SPI interface. Also it can be configured to start measuring from a threshold level programmable. Size: 2x2x0.95mm.

- Microcontroller + Transceiver: device TZ1053 from Toumaz. This is an ultra low power transceiver with a microcontroller incorporated 8051eWarp compatible. It manages communication process by itself and allows us to use it as a microcontroller to run small algorithms. It will be responsible for processing measurements from the accelerometer in to decide whether there has been an impact-based physical event risk (PER), and for the RF communication with the MHPI. Also, it offers the possibility of programming the SAS “Over The Air” (OTA) from the basestation (MHPI). Three operation modes (Processor/Transmit-Receive/Sleep). Size: 5x5x0.9mm.

- Antenna: omnidirectional antenna model 0868AT43A0020 from Johanson Ceramic Technology. Size: 7x2x0.8mm.

- Battery: model cell battery Zinc / Air VARTA Power One p13 (1.42V). Size: 7.9mm (diameter) x5.4mm (height).

- DC-DC Converter: step-up model Austriamicrosystems AS1323. Size: 3x3x0.9mm.

Accelerometer and the microcontroller communicate via SPI bus. The transceiver works in the ISM frequency bands (868MHz).

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[2] According to the conclusions drawn by Bouten [9], the amplitudes of the accelerations involved in human movement during walking, measured at the lower back, are between -0.2g and 0.8g, while running can reach amplitudes of up to 5g. Many works like for instance Najafi et al. [16] assumes that a sensor with range ± 2g is enough to monitor the elderly.

Another relevant consideration is the multimodal nature of the architecture; this is the possibility to capture other physical magnitudes such as temperature or heart rate, by other smart sensors coordinated by the Smartphone. To this end, our architecture can be extended by an external microcontroller to provide additional processing capacity to the system.

Figure 3 shows a 3D model of our prototype; with dimensions around 20 x 20 x 8 mm. Current advances in our group are reducing these dimensions.

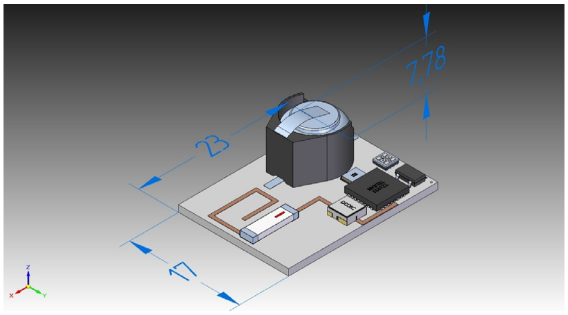

Figure 3. 3D model of the smart accelerometric sensor (SAS), showing the main integrated circuits and dimensions (mm).

3.2 Operating Mode

The consumption of the sensor is modulated by its mode of operation, in turn linked to the signals distributed processing technique. The definition of an optimal operation pattern becomes a critical issue in the design of our sensor, in order to achieve optimal consumption. Fig. 4 presents the basic aspects of the operating cycle of the SAS, without going into details of adaptive algorithm. Workflow shown in Fig. 4 runs in parallel with other workflow focused to the communication between SAS and MHPI. A detailed description of the communications appears in [12]. A brief description of Fig. 4 follows:

- The CMA3000-D01 VTI accelerometer is normally operating in Motion Detection Mode. In this mode it operates at a sampling rate of 10Hz and a range of 8g. If motion is detected over the threshold level automatically switches to Measurement Mode with a sampling frequency of 100Hz and a range of user-configurable g. When it changes of operation mode an interrupt at pin INT is triggered.

- The microcontroller TZ1053 Telran transceiver normally works in Sleep Mode. When it receives an interrupt from the accelerometer, it switches to Processor Mode. It reads values measured by the accelerometer through SPI, storing them, and running a novel adaptive algorithm to determine whether there has been an impact.

- After motion is detected, energies associated with physical activities are computed. It these ones are not high enough (thresholds are customized to the user), then TZ1053 concludes no-impact and it compels the accelerometer to pass to Motion Detection. TZ1053 switches subsequently to Sleep mode.

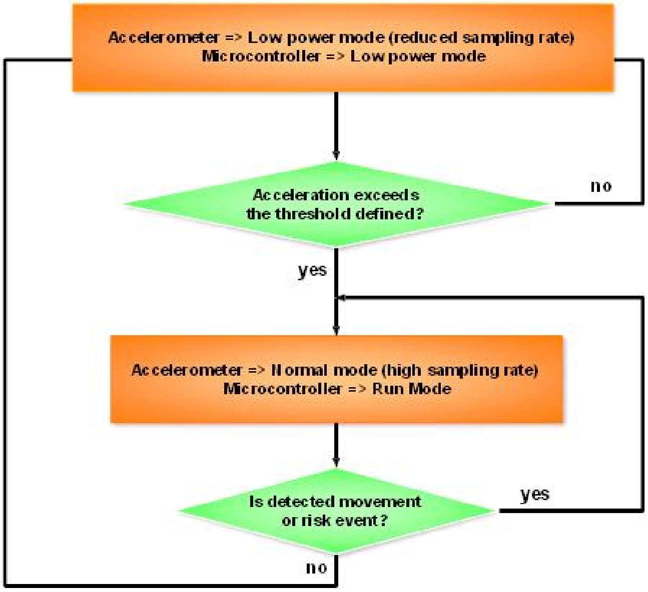

Figure 4. Simplified operating flow associated with signal processing in SAS.

- With a periodicity of T seconds MHPI transmits a frame to SAS via RF to test whether it is still active. When TZ1053 receives the frame, it will switch to Transmit / Receive Mode and will begin communication with the MHPI. In the case of acceleration data stored (impact detected) Telran TZ1053 must send this information to the MHPI. Once communication ends, TZ1053 switches to Sleep mode.

At intervals of nT MHPI transmits a frame to SAS via RF to request a complete state of activity of the subject.

The electrical schematic of SAS is shown in Fig. 5.

Table 1. Power consumption of internal elements

<table>
<tr><th>Component</th><th>Model</th><th>Sleep</th><th>Processor</th><th>Tx/Rx</th></tr>
<tr><td>uC + Transc</td><td>TZ1053</td><td>5µA</td><td>0.8mA</td><td>3.3/3.1 mA</td></tr>
<tr><th>Component</th><th>Model</th><th colspan="2">Detection Mode</th><th>Measurement Mode</th></tr>
<tr><td>Accelerometer</td><td>CMA3000-D01</td><td colspan="2">9µA</td><td>70µA</td></tr>
<tr><th>Component</th><th colspan="2">Model</th><th colspan="2">Typical</th></tr>
<tr><td>DC-DC</td><td colspan="2">AS1323</td><td colspan="2">9µA</td></tr>
</table>

3.3 Autonomy

Theoretical consumptions of main internal electronic elements are shown in Table 1.

In the main operating pattern, SAS links every minute with the MHPI. Assuming that SAS is in Run Mode (accelerometer in Measurement Mode and TZ1053 in Processor Mode) 50% of real time (associated with a high energy activity pattern), Matlab/Simulink simulations give 30 days of autonomy for the proposed battery.

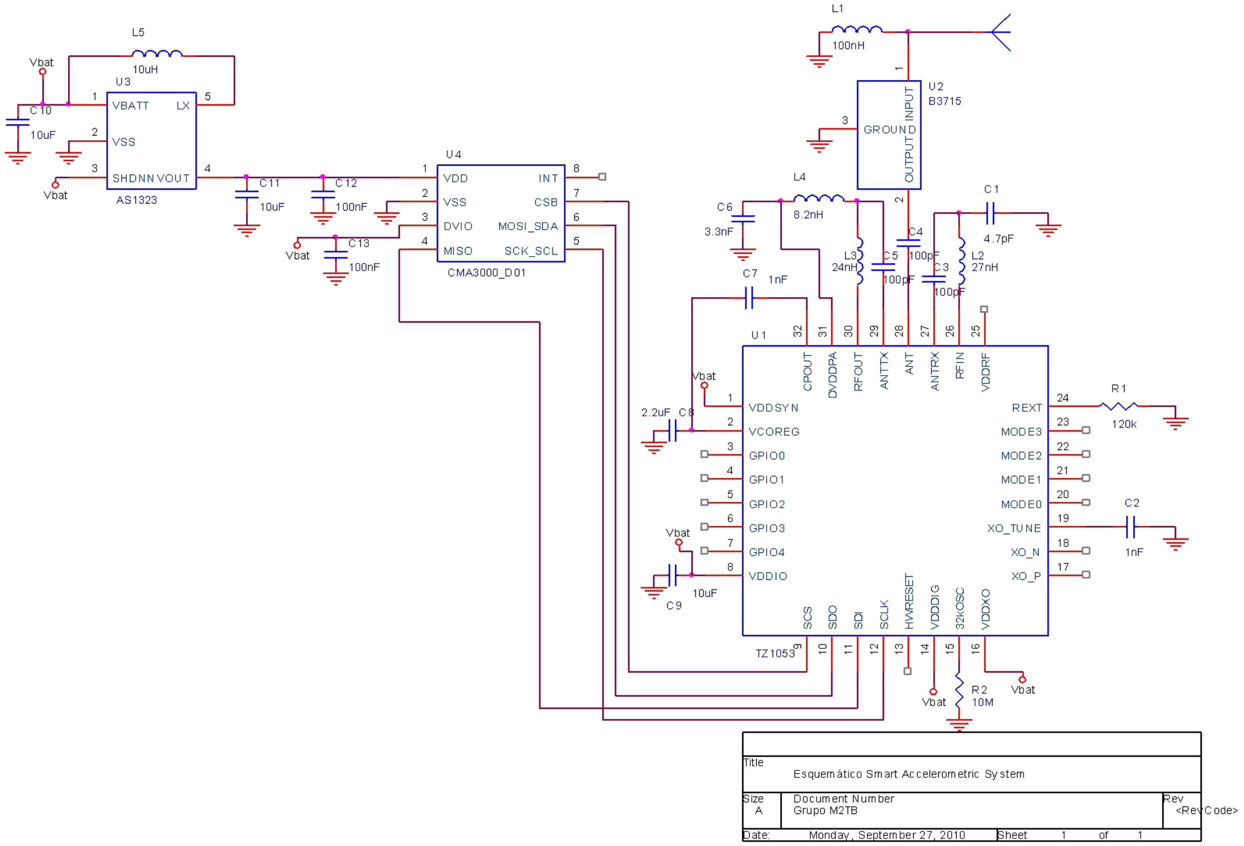

Figure 5. Schematic electronic model of SAS.

3.4 Energy based anisotropic algorithm

A complete description of the methodology followed in the algorithm exceeds the scope of this paper, which addresses only a succinct analysis of its evolution and new approaches.

A key issue in the reliability of this system is given by the development of a low-cost algorithm to be executed in the SAS, which will be able to detect impacts. We start with the impact detection algorithm presented at [11, 17]. An evolved new algorithm was subsequently commented in [11] and has been recently submitted to an international journal. Both algorithms were tested against data obtained from (ADXL202E) in a laboratory study over voluntaries.
The first algorithm follows a 4-axes isotropic energy –amplitude method. Firstly it was proved that the performance improves when the algorithm parameters are personalized to the subject. The new one uses 3 axes because the lower cost, size and easier assembly. As the sensitivity of the impact detector increases with the number of axes, it had to compensate the reduction from 4 to 3 axes. This goal was achieved with the design of a 3-axes anisotropic energy method. As advanced in [11], the 3-axes anisotropic energy method strongly improved the performance of the detection.

We have later tested this evolved algorithm against data obtained from the selected accelerometer (CMA3000-D01) in a laboratory study over voluntaries. This last study tested different body positions to quantify the reliability of the accelerometric subsystem of SAS, with successful results. These outcomes will be submitted to a journal in a short time.

4. DISCUSSION AND CONCLUSION

This paper has presented the technological and functional design solution of a smart wearable accelerometric sensor. Small size and autonomy estimated allow us to have a SAS who can be fixed at different positions (for example with sticking plasters, even be worn on ornaments like bracelets, etc.).

We have developed an adaptive and very light algorithm that can be implemented in TZ1053 (using its “load over the air” feature) without an external microcontroller. The absence of an external microcontroller is one of the important achievements of the design that support the extremely low power consumption.

Laboratory studies carried out with partial subsystems of our prototype have confirmed the reliability of the algorithm, as well as the power consumptions presented here. This way, we have performed benchmarks of battery operation following different operation patterns of SAS, with successful outcomes.

These achievements have been complemented with perception analysis concerning the style, weight and use of different fixations modes of the SAS. A remarkable conclusion of them is that SAS can change its body position, keeping its high sensitivity and selectivity. These studies are being completed and will be submitted in a short time.

In summary, our findings point to the possibility of developing a reliable industrial smart monitor that offers a high reliability together with discretion and usability. This novel smart monitor is patent pending [18].

5. ACKNOWLEDGMENTS

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