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Design of a wearable protection system to prevent fall injuries using Arcadia/Capella tool

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Abstract

This work presents a new wearable protection system incorporating two sensors (3D accelerometer and pressure sensor), with computational capability to inflate small airbags upon detecting a fall, in order to safeguard the elderly from injuries. The proposed concept uses PyroMEMS as pyrotechnical initiators ensuring fast and efficient airbag triggering. To achieve the full design process of this complex system, we adopted a systemic methodology based on Arcadia method using Capella tool.

Key words: Systems Design and Engineering elderly health monitoring, PyroMEMS

Introduction

Unintentional falls are the leading cause of fatal injuries and the predominant reason for nonfatal trauma-related hospital admissions among adults in this age group. Worldwide, each year, around 684,000 individuals succumb to falls, and 37.3 million incidents necessitate medical intervention due to their severity [1]. In this context, wearable protection systems incorporating one or more sensors, alongside computational capability to deploy small airbags upon detecting a fall, can play a pivotal role in elderly care. In this paper, we present the design of a wearable protection system, that can be seamlessly integrated into lightweight belts containing two airbags, positioned on each side of the hips. It uses PyroMEMS as pyrotechnical initiators ensuring fast and efficient airbag triggering.

Methodology

A wearable protection system to protect injuries upon a fall in elderly individuals is a complex system which must adhere to strong constraints among which high reliability, high safety and security, low consumption, low weight and medium cost.... Its design encompasses mechanical, electronic, IT (Information Technologies), and data management aspects. Therefore, we choose to follow a model-based systems design and engineering method (MBSE) using Arcadia/Capella tool [2]–[6]. The use of MBSE enables all aspects of the system to be taken into account, from requirements definition to detailed design and validation, guaranteeing consistency and traceability throughout the design process. The Arcadia/Capella inspired by UML/SysML and NAF standards is the result of an iterative definition process driven by systems and software architects working in a broad spectrum of business domains (transportation, avionics, space, radar, etc.).

It enforces an approach structured on successive design phases which establishes clear separation between needs (operational need and system need analyses) and solutions (logical and physical architectures), in accordance with the IEEE 1220 standard.

Operational and System needs Analysis

As a first step we conduct an inventory of the requirements that the system must fulfill to generate its intended outcomes: *preventing injuries* in the event of a fall and *alerting emergency services*. We consider one single operator who is the person carrying the system (termed as Senior), and one single scenario, which encompasses daily living activities. During this scenario, the operational activities, are as follows:

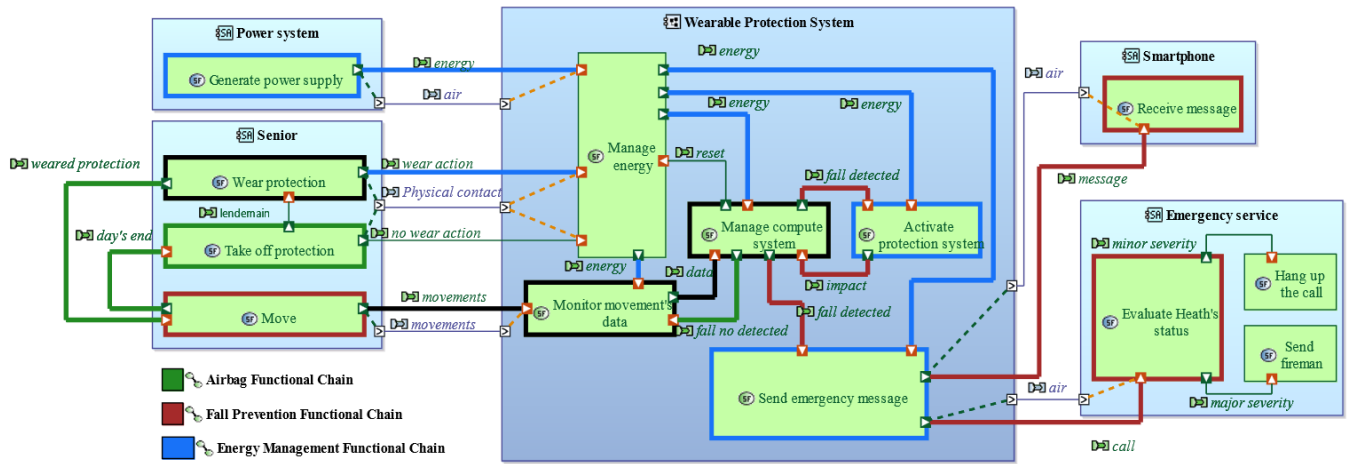
- 1) wearing the system in operation for more than 6 hours
- 2) removing the system at the end of the day
- 3) stumbling, falling, and preventing injuries
- 4) calling for assistance. Indeed, following a fall, if the person is injured, he/she would require the ability to call an emergency service.

These operational requirements provide crucial specifications for subsequent physical architecture (section VI) and technological choices (section V): point 1) necessitates a very lightweight and non-invasive system to ensure acceptance, as well as secure attachment when worn. Point 2) underscores the need for the system's attachment to be easily manageable. Additionally, point 2) allows for consideration of a wireless rechargeable system during the night. Points 3) and 4) will feed technical specifications of the system, particularly emphasizing the need for utmost reliability and rapid triggering of the airbag before contacting the ground. Moreover, a communication module will be designed to establish communication with assistance.

Operational requirements can then be formalized in a set of *System Functions* having well-defined inputs and outputs as depicted in Fig. 1 in which the three *System Functions* are *Monitoring and Inflation System*, *Power System*, and the *Smartphone*.

System Analysis and Logical architecture

One of the subsequent steps in progressing towards the Logical Architecture is to develop the Contextual Realization diagram (not shown) and ensure that all the Actors are engaged in at least one *Capability* realization. From this analysis, we derive four System Capabilities: **C1-Monitor Senior's daily activities**, **C2-Detect Pre-impact fall**, **C3-Trigger the inflation**



of the Airbags and C4-Alert the Emergency Service. We then define three Functional Chains to describe the system's behavior within each capability, thus facilitating the piloting of validation tests (refer to Fig. 1) :

- 1) Airbag (C1) : The monitoring device is operational, awaiting a pre-fall occurrence.
- 2) Energy management (C1-C2-C3-C4): Electrical energy is distributed across the system, for the monitoring device and airbags triggering.
- 3) Fall prevention (C2-C3-C4): The monitoring device detects a pre-fall and triggers the inflation of the airbags.

Following this, we establish the complete Logical architecture of each System Function, namely the Monitoring and Inflation System, the Power System, and the Smartphone, refining each into new Logical Functions and components. In this conference paper, we will exclusively present the logical architecture of the *Monitoring and Inflation System*, that can be divided into 5 interconnected modules :

- A. The Sensing Module
- B. The Control Module
- C. The Communication Module
- D. The Gas Generator Module
- E. The Power Supply Module

Physical Analysis and technological choices of the Monitoring and Inflation System

The assessment and selection of technologies constitute a complex and multi-criteria problem. To conduct the Physical Analysis, we grouped the Sensing, Control and Communication Modules in one single physical component termed as *Computer*. Logical modules have been broken down into Behavior physical components and Physical Components, namely *Computer*, *Airbag*, *Power Supply*.

A. Computer Component

Taking into account the operational requirements, we've

opted for a single low-power tri-axis MEMS accelerometer (LIS3DH from STMicroelectronics) and a barometric pressure sensor (ICP-20100 from TDK). The selected type of exchange is SPI for the accelerometer and I2C for the barometer. The Control Module comprises a System-on-Chip (SoC - nRF52832 from Nordic Semiconductor), which is a low-power consumption QFN48 integrated with Bluetooth Low Energy (BLE) interface, utilized for communication with a cell phone. The SoC communicates with the cephone via BLE to transmit the following: In the event of a fall, the system sends a warning signal to the phone through a 2.4 GHz antenna. Subsequently, the user has the option to either contact the fire department or reset the system. Additionally, for debugging purposes, sensor values are transmitted to the phone and stored.

B. Power Supply Component

We use a 3.7V LIPO battery, with a BUCK IC to convert the voltage range from 3.7-4.2V to a stable 3V for the power supply system. Having in mind security requirement, we opted

for a magnetic switch (RR122-1A52-511 from Coto Technology) between the power supply and the system. A P-channel MOSFET is employed for ON status control. In a normally-open design, the sensors' outputs remains HIGH when no magnetic field is detected, preventing the P-channel MOSFET from turning ON and thereby inhibiting current flow through the system. However, when a magnet approaches and generates sufficient magnetic flux density, the sensors' outputs switch to LOW, reducing the Vgs of the MOSFET to a level where the source-drain channel turns ON, thus activating the system. The system can be recharged using a wireless IC (BQ51050B from Texas Instruments) compliant with the WPC 1.2 norm.

C. Airbag Component

To initiate the decomposition of an energetic materials, we employ a PyroMEMS [7]-[9]. This 4x2 mm² igniter consists of a Ti bridge deposited on a glass substrate, as illustrated in Figure 2. Atop the Ti resistance (approximately 50 Ω), a

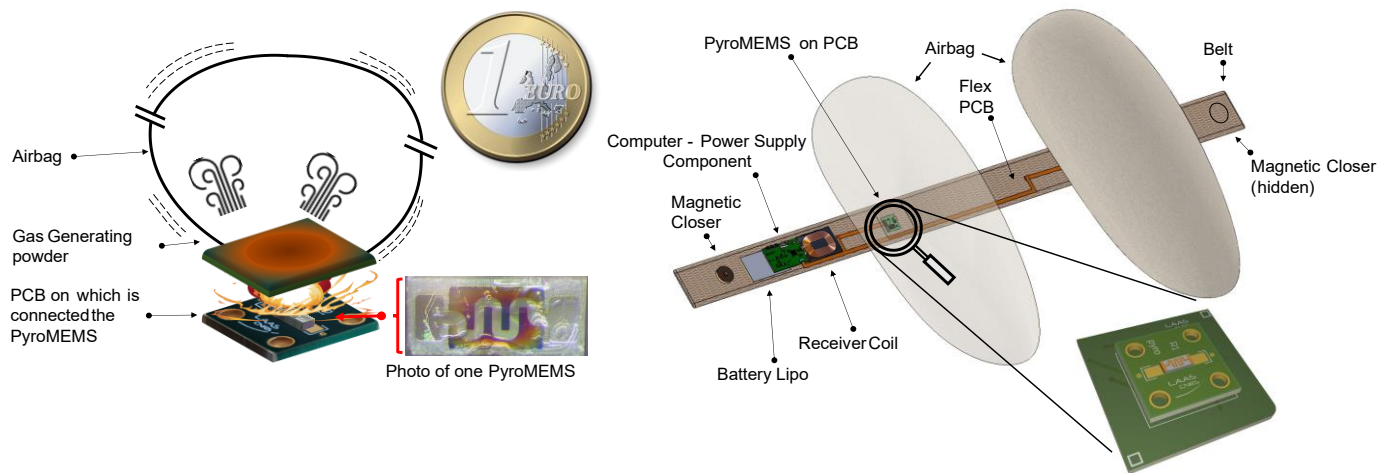


Fig. 2. Physical design of the wearable protection system

reactive thin film of Al/CuO thermite is deposited. Upon ignition within 100 μm [10] by capacitance discharge, using a capacitor of 10 μF under 16 V, the thermite produces a spark which then ignites a specific energetic materials specifically designed to generate gas [11]. A converter is employed to boost the voltage from the 3 V supplied by the LiPo battery to 16 V under a load of up to 200 mA. Subsequently, we add a linear current source for two purposes: firstly, to verify PyroMEMS connectivity through a small current (< 5 mA); secondly, to charge the capacitor with a constant current (minimum 200 mA). A MOSFET circuitry is employed to regulate the current value. It has to be noted that before charging the 10 μF capacitor to 16V the MCU checks the resistance of the PyroMEMS using an amplifier IC working at , the capacitor is charge and PyroMEMS ignited.

Physical Architecture

The proposed physical design of the system is depicted in Fig. 2. The belt, made of cotton, incorporates magnetic closures and non-magnetic closures at each end. The electronics are housed within the belt. The battery is inserted in an internal pocket on the belt, allowing easy access in case of change. The receiver coil for charging is also in the belt, so that there is a 3.4 mm distance between the receiver coil and the WPC 1.2 wireless charging port. Electronic boards are interconnected using a flexible printed circuit board (PCB). Connected directly to the previous board, a small PCB containing the PyroMEMS is superimposed with a layer containing the pyrotechnical materials enabling the gas generation after ignition to protect the Senior from being injured.

Conclusion & Future Work

A wearable protection systems incorporating two sensors, with computational capability to inflate small airbags upon detecting a fall, was designed using Arcadia/Capella method. Future work will involve engineering each component of the system, verifying their functionalities individually, before assembling the entire system as a crucial demonstrator to be

tested in real-life conditions with elderly individuals.

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