Smart clothing to increase safety of people with dementia

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Abstract: Human population is aging. Therefore, considerable amount of attention has to be given to the problems specific to aging. Dementia is one of such problems. There is a strong relation between dementia and gait disorders. With aging the amount of people falling during standing, walking or climbing stairs dramatically increases. Because of this, the elderly people have a greater need for care and assistance and are more likely to be admitted to a nursing home after a fall, although they would like to stay at their own home and be independent. Although a number of researchers are dealing with this problematics so from the point of the medical diagnostics, as from view of possibility of integrating fall detection device into clothing, there are still unresolved problems on the area of providing safety of people with dementia. This contribution deals with the integration of a fall detection system being supplied by printed batteries into clothing, designed with medical function in mind for safety of elderly people and patients with dementia. The first part presents a fall detection and long-term motion monitoring system and considers its power consumption. Energy consumption will be considered based on an amount of current consumed by particular parts of fall detection and long-term monitoring system. The second part gives an overview of various batteries suitable to supply the fall detection and long-term motion monitoring system integrated into clothing, while the third part presents suggestions for fall detection and long-term motion monitoring system integration into clothing.

Keywords — Dementia, fall detection system, printed batteries, smart clothing.

I. INTRODUCTION

Dementia is becoming an increasing problem of modern society, as the number of patients, due to the aging of population, is steadily increasing. According to the World Health Organization (WHO), worldwide around 50 million people have dementia, and there are nearly 10 million new cases every year. The most common form of dementia is Alzheimer's disease and may contribute to 60–70% of cases [1]. Dementia is one of the major causes of disability and dependency among older people worldwide. There is a strong relation between dementia and gait disorders. With aging the amount of people falling during standing, walking, climbing stairs, etc., dramatically increases. For example, at the age of 60 only 15% of people has gait disorders and 85% of people has no gait disorders. The situation is reversed at the age of 85 when 82% of elderly people have gait disorders and only 18% has no gait disorders [2], [3]. Elderly people have a greater need for care and assistance and are more likely to be admitted to a nursing home after a fall, although they would like to stay at their own home and be independent [4]. Falls are a problem for elderly people because of fall related injuries as well as a fear of falling. The latter is related to the fear from ‘long lie’ which means involuntary laying in the floor for an hour or more after the fall because ‘long lie’ may result in medical complications [3].

Many wearable (electronic) devices with the ability to detect falls and capturing of gait were developed recently [3], [5–10]. Some of them were developed for medical diagnostics while some were developed with functionality to start intervention after a fall and thereby support elderly people to be independent and to live in their own homes.

Research experiments as well as medical diagnostics are time limited and usually short in time. In addition, both are usually performed within specialized environment. In such cases mounting of specialized sensor equipment on the body by band is acceptable. To guarantee continuous safety of elderly people and especially people with dementia a much better solution is integration of fall detection system into human clothing. In this area may be exposed to research of an integration of fall detection device into clothing, i.e. custom vest or smart skirt [11], [12].

This contribution deals with the integration of a fall detection system being supplied by printed batteries into clothing, designed with medical function in mind for safety of elderly people and patients with dementia. The first part presents a fall detection and
long-term motion monitoring system and considers its power consumption. Energy consumption will be considered based on an amount of current consumed by particular parts of fall detection and long-term monitoring system. The second part gives an overview of various batteries suitable to supply the fall detection and long-term motion monitoring system integrated into clothing. Battery capacity given in mAh and battery life will be considered and batteries selected. The third part presents suggestions for fall detection and long-term motion monitoring system integration into clothing.

II. FALL DETECTION AND LONG-TERM MOTION MONITORING WEARABLE SYSTEM

There have been many fall detection and motion monitoring wearable systems hardware and software configurations designed, built and evaluated. The construction of the majority of fall detection and motion monitoring wearable systems resembles the construction of sports activity monitoring device. They are designed as a self-contained one unit (box) rigid device attached to the human body by a band or a patch. And they possess the ability to store measured data and to send measured data by wireless communication to a stationary computer or a mobile phone. Such a design makes the fall detection and motion monitoring wearable systems suitable also for use as a short-term gait diagnostic device in medicine. Unfortunately, such a design of fall detection and long-term motion monitoring wearable device is not suitable for elderly people and people with dementia. It is also not suitable for long-term unobtrusive motion monitoring of people who are under long-term monitoring due to a risk of dementia development. In the case of fall detection and motion monitoring system design for people with dementia the short-term memory impairment of the people of dementia appearing already at an early stage of the disease should be considered. People with dementia and elderly people might be able to remember events that took place years ago, but they cannot remember where they left an item, why they entered a particular room or what they were supposed to do on a given day. Due to this they frequently forget to take fall detection and motion monitoring device with them. Therefore, the best solution is the integration of the fall detection and motion monitoring device into their clothing.

Today electronic devices are developing very fast. Main development directions of electronic devices are increasing integration, reduction of power consumption, flexibility and stretchability. Increasing integration and reduction of power consumption lead to reduction in size and weight of electronic devices and/or to increase of lifetime of battery powered electronic devices. New technologies of organic and printed electronic contribute to introduction of flexibility and stretchability of electronic devices. All mentioned trends contribute to easier integration of wearable electronic devices into the clothing.

To provide functionality of human fall detection and motion monitoring the wearable device consists of motion sensor(s), a microcontroller, an additional memory, a wireless radio frequency communication and a power supply. The motion sensor, microcontroller and additional memory are connected by a wired communication. The fall detection and motion monitoring wearable device is connected by wireless communication to the stationary computer or to a mobile phone being a gateway to the Internet (Internet of Things), Fig. 1. Particular functions of the fall and motion monitoring device may be integrated – depending on an implementation of electronics.

Motion sensors – Inertial measurement unit (IMU) used in fall detection and long-term monitoring device might consist solely from 3-axis accelerometer or from 3-axis accelerometer and 3-axis gyroscope or from 3-axis accelerometer, gyroscope and compass. To detect human body posture 3-axis accelerometer or 3-axis compass may be used. The body posture using 3-axis accelerometer is determined by the use of earth’s gravity acceleration.

Therefore, fall detection devices are sensitive to the position and orientation on the body it is to where they are worn or attached to the body or clothing [11]. Fix attachment of the fall detection device is necessary. The most suitable position of a fall detection device motion sensor was found to be at the waist [6], [9]. Other considered body or clothing
attachments up to day include attachment on the shoes [7], on an ankle [5], on a tight, to the chest [10], upper arm, on a wrist. For instance, ActivePal which has become a reference device for activity of daily life (ADL) measurements is attached to a tight by a patch. A solution of walking pattern detection by an accelerometer inside a smart (mobile) phone worn in a small pocket was proposed in [8]. The smart mobile phone used in this latter case was placed and oriented in the pocket by a responsible person. Measured motion data are sent from motion sensors to the microcontroller. Motion sensors are frequently used in battery powered electronic devices therefore they are designed to operate with minimal current consumption while fulfilling application demands. They posses low power modes, programmable data output rates, programmable measurement ranges, interrupts, auto-wake/sleep function, etc. all in order to enable minimal current consumption. Table 1 shows data for current consumption of two motion sensors: the 3-axis accelerometer MMA8451Q and MPU6050 6-axis motion (3-axis gyroscope + 3-axis accelerometer) MEMS motion tracking device with regard to acceleration low power mode operating currents.

The MPU6050 consumes 3.8 mA at full power, it is with gyroscope measurements at all rates and acceleration at 1000 Hz. Both motion sensors could be supplied with 3V.

The most frequently used options for sending data to the microcontroller are SPI, I2C and UART communication. Energy consumption increases from SPI (the lowest), over I2C to the highest consumption of UART.

| TABLE I | MOTION SENSOR CURRENT CONSUMPTION |
|---------|----------------------------------|
| MMA8451Q | Current [μA] | MPU6050 | Acceleration rate[Hz] | Current [μA] |
| 1.56    | 6/165            | 1.25          | 10                      |
| 6.25    | 6/165            | 5             | 20                      |
| 12.5    | 6/165            | 20            | 70                      |
| 50      | 14/165           | 40            | 140                     |
| 200     | 44/165           | -             | -                       |

Power consumption of the microcontroller (MCU) depends on processor type (8-bit, 16-bit, 32-bit), the clock/speed of calculations, the amount of calculations (processing power) needed in an algorithm used for fall detection if it is implemented on the microcontroller and many other power-saving features, like: unneeded peripheral module disable, low power watch dog, idle and sleep mode, programmable clock frequencies, etc. MCU sleep mode halts all clock operation, halts all code execution and almost all peripheral operation. In sleep mode MCU current consumption is reduced to a minimum. Idle mode halts the code execution but allows peripheral modules, for instance: communication, to continue operation. Table 2 shows current consumption data for power down mode of 8-bit PIC18F25K22 microcontroller and 16-bit dsPIC33FJ64MC802 micro-controller with digital signal processing engine (40-bit data registers).

| TABLE II | 8-BIT MCU PIC18F25K22 AND 16-BIT MCU dsPIC33FJ64MC802 CURRENT CONSUMPTION |
|----------|---------------------------------------------------------------|
| Module mode | 8-bit PIC 18F25K22 at 3V supply | 16-bit dsPIC33FJ64MC802 at 3.3 V supply | Clock |
| MCU sleep | Current min/max [μA] | all stopped | MCU sleep | Current min/max [μA] | 28/87 | all stopped |
| MCU idle | 14/35 | 32 kHz, secondary | MCU idle | - | - |
| MCU idle | 80/150 | 1 MHz, primary | MCU idle | - | - |
| MCU idle | 750/1000 | 20 MHz, primary | MCU idle | 8000/1000 | 20 MHz, primary |
| MCU run | 19/50 | 32 kHz, secondary | MCU run | - | - |
| MCU run | 200/300 | 1 MHz, primary | MCU run | - | - |
| MCU run | 2650/3500 | 20 MHz, primary | MCU run | 18000/22000 | 20 MHz, primary |
| watch dog | 0.5/0.5 | - | watch dog | 10/15 | - |

The data in Table 2 show that greater processing power means also considerably higher current consumption. According to the available battery power we might decide whether to implement fall detection algorithms on the battery powered fall detection and motion monitoring device or on the stationary computer which is also a gateway to internet and has power is available through the wall outlet or on mobile phone. Depending on this decision we also select the appropriate microcontroller (with high or low computing power) for fall detection and motion monitoring device.

Microcontroller sends processed or unprocessed data to the wireless communication module using SPI, I2C or UART communication. If the motion data are processed on the microcontroller of the fall detection and motion monitoring device, then...
Taking into account the average power consumption (current) $I_{\text{ave}}$, equation (2):

$$I_{\text{ave}} \ [\text{mA}] = \text{sum} \ (I_{\text{motion\ sensor}} + I_{\text{MCU}} + I_{\text{Bluetooth}} + I_{\text{peaks}}) = 0.2 \ mA + 3 \ mA + 0.3 \ mA + 0.25 \ mA = 3.75 \ mA \ (2)$$

alarms to start intervention via wireless communication must be send in the case of a detected fall. Otherwise quite a lot of motion data (accelerations, speed, orientation) should be periodically sent to the stationary computer and internet gateway where a fall detection algorithm is run. Therefore, current consumption of wireless communication is another important data for the battery supplied fall detection and motion monitoring device design. Table 3 shows current consumption of frequently used wireless communications all using 2.4 GHz ISM band Data in table 3 show that current consumption of wireless communications is considerably lower than the consumption of microcontroller and motion sensors. WiFi has the highest current consumption, Standard Bluetooth and ZigBee have middle current consumption with peak currents between 30 mA and 60 mA. The lowest current consumption have NRF24L01 and Bluetooth low energy with peak current consumption around 10 mA. Due to the nature of wireless protocols (many short time peaks) the average current consumption of wireless communication is much lower than show values of maximum current consumption.

| Wireless communication | Range   | Tx Current consumption | Rx current consumption | Current in sleep | Data rate |
|------------------------|---------|------------------------|------------------------|------------------|-----------|
| WiFi (WGM 110)         | 450 m   | 261 mA                 | 81 mA                  | 22 μA            | 72 Mbps   |
| low power WiFi (RN171) | 150 m   | 120 mA                 | 40 mA                  | 4 μA             | 24 Mbps   |
| Bluetooth (WT12)       | 30 m    | 60 mA                  | 7 mA                   | < 1 mA           | 2 Mbps    |
| Bluetooth low energy (RN4871) | 150 m | 10 mA                 | 10 mA                  | 2.9 μA           | 10 kbps   |
| nRF24L01               | 100 m   | 11.3 mA                | 12.3 mA                | 0.9 μA           | 2 Mbps    |
| ZigBee [CC2530]        | 30 m    | 30 mA                  | 24 mA                  | 1 μA             | 250 kbps  |

Therefore, for estimation of average current consumption the current consumption values in sleep (longer time periods between peaks) are important. If Bluetooth low energy RN4871 (based on IS1870) is used then according to data during advertising peak currents of 12 mA appear, but the average current during advertising is around 230 μA. Such a current consumption is comparable with maximal current consumption of motion sensor.

An overall power consumption of the fall detection and long-term monitoring device is obtained as a sum of average current consumption values of motion sensor, microcontroller including SPI or I2C communication and wireless communication. Based on the obtained data and an assumption of 8-bit microcontroller based fall detection device that 3V supply is needed which is capable of providing short-time 10 mA peak currents and average current around 1 mA.

III. POWER SUPPLY FOR FALL DETECTION AND LONG-TERM MONITORING WEARABLE DEVICE

For the supply of fall detection and long-term monitoring wearable device batteries are needed. Standard batteries are cylindrical, for instance AA or smaller AAA type of batteries. AA and AAA batteries are rather big, heavy and thick to be used in wearable devices integrated into clothing. More convenient batteries for integration into clothing are coin battery cells and flat Li/ion batteries. Both are flat, rather small and thin, but still rigid. The last type of batteries we are going to consider are printed batteries. The shape of printed batteries seems to be the best for integration into clothing. Printed batteries are thin, it is less than 1 mm thick, and flexible. They could be attached to a curved surface with a minimum radius of 25 mm.

Table 4 shows comparison of considered battery data, like dimensions, weight, voltage, capacitance and internal resistance. All batteries in Table 4 are primary except VARTA V 150H which is rechargeable battery. Enfucell batteries are printed batteries thin as a paper sheet.

For good operation of fall detection and long term monitoring device Table 3 shows that fairly high current is needed for wireless communication. The lowest maximal values of current supply needs Bluetooth low energy (RN4871) 10mA, but the lowest speed of data transfer. Next lowest maximal current supply needs nRF24L01, it is up to 13mA and highest speed of data transfer 2 Mbps. And after nRF24L01 the maximal current supply needs ZigBee (30mA, 250 kbps data transfer speed).

An overview of batteries in Table 4 shows that new Enfucell batteries 1.5V PLUS could provide sufficient current even for maximal current demands. But we have to connect two batteries in series to get the 3V voltage supply level for the fall detection device. Internal battery resistance doubles and the maximal available current decreases if two batteries are connected in series. To be able to run fall detection and long-term monitoring device with some margin in maximal current we connect additional two batteries in parallel to the previous two batteries. Altogether we now use four batteries to supply our fall detection and long-term monitoring device. The following power consumption of the fall detection and long-term monitoring device can be estimated, Table 5.

Estimated battery voltage drop due to maximal current peaks is expressed as:

$$U = U_0 - R*I_{\text{max}} = 3 \text{ V} - 50*0.015 = 3 \text{ V} - 0.75 \text{ V} = 2.25 \text{ V} \ (1)$$

According to data of motion sensor, microcontroller, Bluetooth and memory all four work satisfactory at voltage supply 2.25 V. Taking into account the average power consumption (current) $I_{\text{ave}}$, equation (2):

$$I_{\text{ave}} \ [\text{mA}] = \text{sum} \ (I_{\text{motion\ sensor}} + I_{\text{MCU}} + I_{\text{Bluetooth}} + I_{\text{memory}}) = 0.2 \ mA + 3 \ mA + 0.3 \ mA + 0.25 \ mA = 3.75 \ mA \ (2)$$
TABLE IV
AVAILABLE ELECTRICAL POWER BY BATTERY TYPE, SIZE AND CAPACITY

| Name            | Shape | Weight m [g] | Dimensions [mm] | Thickness h [mm] | Un [V] | R [Ω] | I [mA] | Im [mA] | C [mAh] |
|-----------------|-------|--------------|-----------------|------------------|--------|------|--------|--------|--------|
| VARTA HE AA     | cyl   | 23.8         | 50.0            | 14.0             | 1.5    | 0.2  | 200.0  | 1000   | 2960   |
| VARTA HE AAA    | cyl   | 11.0         | 44.0            | 10.0             | 1.5    | 0.2  | 20.0   | 1000   | 1250   |
| VARTA V 150H    | oval  | 6.0          | 25.5            | 5.725            | 1.2    | 0.8  | 28.0   | 280    | 150    |
| VARTA CR2032    | coin  | 3.0          | 19.8            | 3.0              | 3.0    | 16.0 | 0.2    | 10     | 230    |
| ENFUCELL PLUS   | sheet | 2.9          | 72 x 60         | 0.7              | 1.5    | 25.0 | 1.2    | 18-20  | 90     |
| ENFUCELL        | sheet | 2.9          | 72 x 60         | 0.7              | 1.5    | 50.0 | 0.6    | 8-10   | 90     |
| ENFUCELL PLUS   | sheet | 1.4          | 60 x 42         | 0.7              | 3.0    | 150.0| 0.4    | 6      | 10     |

TABLE V
ESTIMATED POWER CONSUMPTION OF THE FALL DETECTION AND LONG-TERM MONITORING DEVICE

| Un [V] | R [Ω] | Iave [μA] | Imax [mA] | C [mAh] | Dimensions [mm] | Weight [g] |
|--------|-------|-----------|-----------|--------|-----------------|------------|
| 3      | 50    | 3750      | 15 mA     | 180    | 288 x 120       | 23.2       |

The battery lifetime $t_{b, lif}$ can be expressed according to equation (3):

$$t_{b, lif} = \frac{C [mAh]}{I_{ave} [mA]} = \frac{180}{3.75} = 48 \text{ h}$$  (3).

At the assumed power (current) consumption, the four printed batteries sewn into the clothing would have a lifetime of 48 hours working round the clock. Then they would be replaced. The 48 hours seems a reasonable long time to start implementation of the device.

IV. INTEGRATION OF THE FALL DETECTION AND LONG-TERM MONITORING DEVICE INTO CLOTHING

In previous works was found that the most suitable position of the fall detection device is around the waist. Therefore, we decided to integrate the fall detection and long term monitoring device into women’s trousers. The specific intended integration of a fall detection system, supplied by printed batteries into clothing, required development a functional pattern, which will provide easy to use. For this purpose was ergonomically designed women’s trousers, with minimum inhibitory effect on movement and provide suitable comfort and performance to the user.

The sketch of women’s trousers, designed with medical function in mind for safety of elderly people and patients with dementia, enable the integration of a fall detection system and printed battery into lumbar part of the belt. The sketch of women’s trousers with a designed position for the integration of a fall detection system and printed battery is shown in Fig. 2.

![Fig. 2. Sketch of women’s trousers with a designed position for the integration of a fall detection system and printed battery](image)
From analysis of the results of pattern engineering of the women’s trousers with a designed position for the integration of printed battery is clear that the designed construction solution provides the surface of the battery up to 660 cm², depending on the trousers size. The dimensions of the battery surface according to the women’s trousers size is shown in the Table 6.

| Size designation | Surface area for printed batteries [cm²] |
|------------------|-----------------------------------------|
| 36               | 416.73                                  |
| 38               | 441.86                                  |
| 40               | 467.48                                  |
| 42               | 493.56                                  |
| 44               | 520.14                                  |
| 46               | 547.21                                  |
| 48               | 574.77                                  |
| 50               | 602.83                                  |
| 52               | 631.39                                  |
| 54               | 660.45                                  |

V. Conclusion

The integration of a fall detection system supplied with a printed battery embedded into clothing, designed with medical function in mind for safety of elderly people and patients with dementia, has been investigated. The special attention was devoted to studying the power consumption for the fall detection from the long-term motion monitoring standpoint, which will be integrated into the women’s trousers, as well as to pattern engineering of the women’s trousers. The model of women's trousers was specially engineered to the requirements for the integration of a fall detection system and printed batteries. Energy consumption was investigated from point of view of an amount of current consumed by particular parts of fall detection system.

The results of pattern engineering of the women’s trousers with a designed position for the integration of printed batteries indicates that the designed construction solution provides the surface of the battery up to 660 cm², depending on the women’s trousers size.

According to obtained surface area for printed batteries, and related assumed power (current) of printed batteries, integrated into the women’s trousers, which corresponds a lifetime to about 90 hours working round the clock, the next step of our research will be focused on the implementation of the fall detection system supplied with a printed batteries embedded into clothing.

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