Design of a smart shoe insole to monitor frail older people

Yoann Charlon, Fehd Bettahar, Eric Campo

To cite this version:

Yoann Charlon, Fehd Bettahar, Eric Campo. Design of a smart shoe insole to monitor frail older people. International Conference on Modern Well-being for Societies and Territories, Mar 2013, Sainte Feyre, France. hal-02878102

HAL Id: hal-02878102
https://hal.laas.fr/hal-02878102
Submitted on 22 Jun 2020

Design of a smart shoe insole to monitor frail older people

Yoann Charlon[1,2], Fehd Bettahar[1,2], Eric Campo[1,2]
[1]CNRS, LAAS, 7 avenue du colonel Roche, F-31400 Toulouse, France
[2]Univ de Toulouse, UPS, UTM, LAAS ; F-31400 Toulouse, France
yoann.charlon@laas.fr

Keywords: **Smart insole, elderly monitoring, gait speed, frailty**

Abstract

In this paper, we present the design of a smart insole for frail subject's follow-up. This device embeds some sensors and wireless communication. The smart insole able to measure gait speed and its variability, weight modifications, and daily activity with minimum invasiveness. It performs measurements continuously and automatically during the walking periods, at home and in outdoor environment.

I. Introduction

Prevention of disability represents major healthcare priorities. Frailty is a syndrome determining a higher vulnerability to stressors and responsible for an increased risk of major negative health-related events, including disability [1-2]. Fried et al. criteria are the most commonly used by the medical community to identify frail subjects. The main criteria are: gait speed, poor muscle strength, exhaustion, sedentariness, and involuntary weight loss [3]. In order to encourage sedentary people to practice walking, we propose to develop an economically viable technical device facilitating the follow-up of frail elderly people. The device is a smart shoe insole, able to measure gait speed and its variability, weight modifications, and daily activity with minimum invasiveness. This wireless insole will transmit information to an indoor database which can be controlled from a secure Internet connection in real time. In this paper, we present the general specifications, the design of the smart insole, the method for measuring the gait dynamic parameters, and preliminary results.

II. Global technical solution specifications

The shoe insole is an ambulatory monitoring tool which must measure:

- Activity periods and their durations over time (days, weeks, months);

- For each activity periods the number of steps, speed, distance covered, average speed and maximum speed;
- The weight variation between two time periods.

It must also be able to identify the person and perform accurate and reproducible measurements. Due to the acceptability requirement for the user and economic constraints, the device must be transparent to the user, self-powered, robust and reliable, and low cost.

The smart insole will be placed in an operational set (Figure 1):

- A radio beacon for collecting sensor data;
- A collection terminal (personal computer) with an internet connection;
- A management remote server of a database;
- A Web application used by the person and his doctor via a remote access to view activity data.

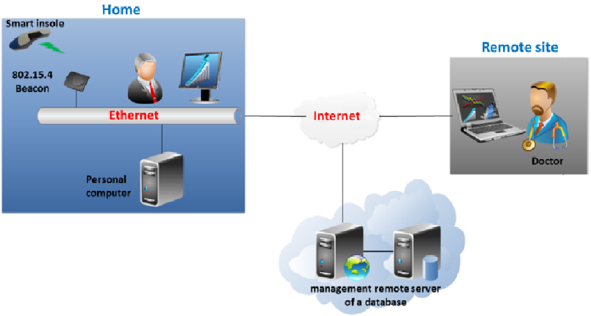

Figure 1. Operational set

III. Hardware architecture

A) Insole prototype design

The energy performance level is an important factor in the technological choices. The Printed Circuit Board (PCB) embedded in the insole includes the following elements: a low power 3-axis acceleration sensor, a System In Package (SIP) including a low power microprocessor unit (MCU) and a 802.15.4 compliant transceiver, a flash memory for local data logging and a nanopower time keeper to activate scheduled data logging modes. This system is supplied by a lithium battery with a capacity of 90 mAh. The size of the device has been minimized in order to embed it in an insole. The dimensions are 3.2cm*2.2cm*3.5mm and a total weight of 5 g (including the battery). Figure 2 shows the smart insole.

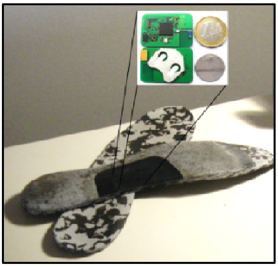

Figure 2. Smart insole

B) Radio beacon design

The beacon device is a radio receiver connected to PC via an Ethernet cable to collecting data from the smart insole. This device is mainly composed of a 802.15.4 transceiver and a RS232/IP gateway. Data received by the Beacon are sent via this gateway to the collecting terminal. The Beacon is powered by the electrical grid via a transformer or by the PC with a suitable USB cable. The radio range between the Beacon and the wireless insole is about 10m. A synchronization protocol must be established to synchronize the data transmission when the wireless insole detects the Beacon.

IV. Method for gait dynamic measurements

A) Material and Method

Accelerometers and gyroscopes are mainly used in the literature [4-6] to measure the dynamic characteristics of walking from the foot position. In our device, we use an accelerometer because it is more compact and is more low power consumption than gyroscope. It is necessary to implement a robust stride detection method because the computing of other parameters is based on this first step. For stride detection, the most reliable algorithm found in literature is proposed by Jiménez et al. [7]. The error is 0.1% for a normal gait speed. Thus, we implemented the algorithm proposed in this publication in order to verify these performances. We added a method to measure cadence. The accelerometer was configured to capture sensor samples at 100 Hz. Algorithm implemented for stride detection and cadence measurement consists of the following 5 steps:

1) Compute the magnitude of the acceleration, a_i, for every sample i:

$$a_i = \sqrt{a_{xi}^2 + a_{yi}^2 + a_{zi}^2} \qquad (1)$$

where x_i, y_i, z_i, are samples acceleration (g) of x, y, z axis.

2) Compute the local mean acceleration value, computed by this expression:

$$\overline{a}_j = \frac{1}{2w+1}\sum_{q=i-w}^{i+w} a_q \qquad (2)$$

where w defines the size of the averaging window (w=15 samples).

3) Compute the local acceleration variance, to highlight the foot activity and to remove gravity:

$$\sigma_{ai}^2 = \frac{1}{2w+1}\sum_{j=i-w}^{i+w} (a_j - \overline{a}_j)^2 \qquad (3)$$

4) Stride detection with two thresholds on the local acceleration variance:

- The first threshold is fixed to 0.2 g in order to detect the rising edge
- The second threshold is fixed to 0.1 g in order to detect the falling edge

5) After stride detection, we use it to compute the local cadence expressed in steps per second (one stride is equivalent at two steps) with a sliding windows on the last three strides (six steps):

$$C = \frac{6}{t_j - t_{j-3}} \qquad (4)$$

where C denotes cadence and the expression "$t_j - t_{j-3}$" denotes the elapsed time at which the last three strides are detected.

Figure 3 illustrates the steps of the stride detection.

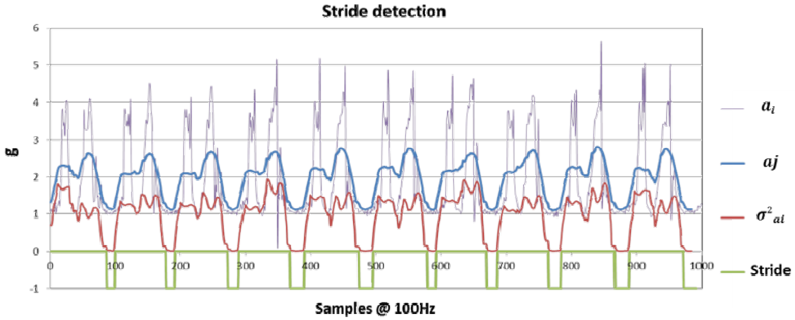

Figure 3. Stride detection process

B) Preliminary results

Measurements performed on a treadmill confirm the robustness of this method. Error on the number of strides is less than 1% over the entire speed range studied (0.5 to 1.5 m/s per step of 0.25m/s). It also appears that the cadence measured is relatively stable for a stable gait speed. Indeed, the cadence variations are about 1% for a stable gait speed over the gait speed range studied. These first tests show a strong correlation between the gait speed and the cadence of a healthy subject. It seems possible to measure walking speed in ambulatory by measuring cadence when the relationship between cadence and gait speed specific to an individual is known. In this perspective a learning phase should be implemented in order to deduce this relationship.

C) Design of a calibration system for the smart insole

A specific tool was designed to calibrate automatically the measures of the insole in a learning phase. This system is based on the use of two light barriers which measure the real gait mean speed on a distance of 4 meters. Each light barrier is composed of an infrared transceiver associated with an optical reflector and a 802.15.4 transmitter. It is supplied by the electrical grid. A 802.15.4 receiver connected to a laptop allows collecting the journey times. Then, software calculates the average walking speed. Figure 4 presents the calibration system of the smart insole.

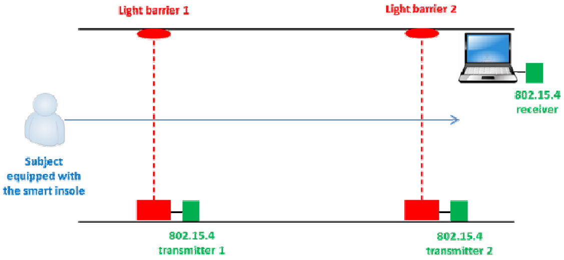

Figure 4. The calibration system of the smart insole

Conclusion

This first version of the insole prototype allowed us to implement the algorithms of the gait dynamic parameters. The stride detection method is robust with an error less than 1% over the entire speed range studied. The first tests show a strong correlation between walking speed and cadence. Nevertheless, these tests must be realized in natural walking conditions with several people. The calibration system proposed is functional. It should allow to calibrate the smart insole when the algorithms will be fixed. In the perspective of an insole self-powered, an energy harvesting system is currently being investigated.

Acknowledgment

The authors would like to thank the financial support provided by DIRECCTE Midi-Pyrénées regional program in France for the Foot-Test project.

References

[1] Ahmed N et al. Frailty, "an emerging geriatric syndrome", Am J Med; 120: 748-53, 2007.
[2] Ensrud KE et al. "Frailty and risk of falls, fracture, and mortality in older women: the study of osteoporotic fractures", J Gerontol A Biol Sci Med Sc; 62: 744-51, 2007.
[3] Fried LP et al. "Frailty in older adults: evidence for a phenotype", J Gerontol A Biol Sci Med Sci; 56:M146-56, 2001.
[4] Sabatini M, et al. "Assessment of Walking Features From Foot Inertial Sensing"; Transactions on Biomedical Engineering; 52, 3, March 2005.
[5] Schepers H, et al. "Ambulatory estimation of foot placement during walking using inertial sensors"; Journal of Biomechanics, 43: 3138–3143, 2010.
[6] Tien I et al. "Results of Using a Wireless Inertial Measuring System to Quantify Gait Motions in Control Subjects"; IEEE Transactions on Information Technology in Biomedicine; 14, 4, 2010.
[7] Jimenez A.R. et al. "A comparison of Pedestrian Dead-Reckoning algorithms using a low-cost MEMS"; IMU, IEEE International Symposium on Intelligent Signal Processing, 2009. WISP 2009: 37-42, 26-28 Aug. 2009.