Feasibility Evaluation of Wearable Sensors for Homecare Systems

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Abstract: Wearable sensors are emerging trend and can be found in various application areas, including healthcare and home care, where they can provide important information about wellbeing, condition and activities of user and his/her behavior. Long-term data analysis can contribute by identification or even prediction of possible diagnosis or threat and for such reason, walking speed and hip extension angle can be useful tools for long-term based behavioral analysis. This article deals with evaluation of method for walking speed estimation and assessment of feasibility of accelerometer for hip extension angle monitoring. While proposed method for walking speed estimation has some limitations, it tends to be reliable. On the other hand, accelerometer for observing hip extension angle is not suitable due to the fact that when it is subject of translational movement, random error it introduced into measurement.

Keywords: Wearable sensors, accelerometer, gyroscope, behavior analysis, homecare.

1. Introduction

Wearable sensors are emerging over last decade and they presents important innovation tool for healthcare and associated services. There are various typical applications of wearable devices such as monitoring of fall detection [1,2], indoor positioning and distance walked [3,4] or physiologic parameters such as ECG [5]. According to EU demographical projections, all members' countries will experience prolongation of life expectancy and effects of ageing the population [6] and thus, there are research activities aimed on development of solutions that would enable good and economically feasible health and social care using diverse technical aids.

The aim of wearable sensors' development is to bring solutions capable of unobtrusive detection of possibly dangerous conditions, such as fall or any other danger, in order to provide either safety of user or to improve his confidence. Such complex tasks can be achieved by integrating wearable solutions into smart environments or households, where stationary sensors are used along with wearable sensors and control system provides supervision and necessary actions. Moreover, by using appropriate algorithms and evaluation techniques, long-term data can be assessed by behavioral analysis and so contribute by prediction of possible threats [7]. General structure of described system is depicted on Fig. 1.

Evaluation of gait velocity has been proven as predictor of adverse events [8] and for this reason its monitoring in smart environment is subject of research and field trials. When considering walking speed, algorithms for its determining can be

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Fig. 1: General structure of complex supervision system for homecare.

categorized into three groups [9]:

■ **abstraction model**, where human body and its physical properties and biomechanics are considered as a black-box model for complex relationship between measurements and walking speed

■ **human gait model**, where predefined model of human gait, either more complex or simple, can be utilized for determining walking speed with stride length

■ **direct integration**, where after defined processing (including defining of starting and ending points of each stride cycle, sensor's orientation, etc.) data are integrated to obtained information about walking speed

Each group of the proposed algorithms uses inertial sensors such as accelerometers, gyroscopes or their combination and different placements of sensors. Our research is aimed on elderly people living alone in their houses or in special care centers, where ambient sensors can be easily implemented and information from wearable devices would provide complementary information about movement activities, activities of daily living or even information that cannot be obtained from stationary sensors such as ECG, blood pressure, etc. For this reason, we decided to place wearable device on hip of user as it can be used for fall detection as well as walking speed estimation and its placement on the belt is natural and at the same time, it is not obtrusive. One of goals of experiment we performed was to assess the suitability of using only three-axial accelerometer for walking speed estimation and possible evaluation of hip move-

ment parameters.

2. Experimental Setup and Methods for Processing and Evaluation of the Results

2.1 Experimental setup

For purpose of evaluation of placement' feasibility, we performed experimental testing with 4 persons involved. Participants were wearing wireless sensors node [2] as shown on Fig. 2, containing three-axial accelerometer, gyroscope and magnetometer, placed in hip area and data were recorded into text file every 16ms. The task of volunteers was to walk on straight line over 11 meters with their usual pace, on concrete floor. Each participant repeated this measurement 10 times, while for first 10 seconds of each measurement, he was ordered to stay still.

Fig. 2: Placement of sensor during experiment and axis orientation.

2.2 Methods for processing and evaluation of recorded data

Incoming data were filtered using low-pass (accelerometer and magnetometer) and high-pass (gyroscope) FIR filter in Matlab for removing noise from raw data. Zero-mean value has been determined over period of 10 seconds to compensate misalignments and to remove Earth's gravity from accelerometer readings or to compensate readings from gyroscope and magnetometer respectively.

For walking speed estimation, method presented in [10] has been implemented according to (1), where v is walking velocity estimate, h is effective length of a leg, $g = 9,81 \text{ m/s}^2$ and $a_{x\min}$ is minimal vertical acceleration of a hip.

$$v = \sqrt{h \cdot \sqrt{1g - a_{xmin}}} \quad (1)$$

In our approach, minimal values of vertical acceleration have been found and value of v has been computed in these time frames. Average walking speed was then computed according to (2), where v_{est} is walking speed estimated as average of n numbers of discrete values of velocity v_i representing also number of steps.

$$v_{est} = \frac{1}{n} \sum_{i=1}^n v_i \quad (2)$$

For comparison, average walking speed v_{avg} was computed as division of distance over time of walking for each measurement. Illustration of such comparison is shown on Fig. 3, where v_{est} and v_{avg} are displayed in the same time frames as velocity estimations v and have constant values.

Fig. 3: Placement of sensor during experiment and axis orientation.

Whole dataset of measurements was subject to above mentioned processing and computed results were compared. Tab. 1 summarizes averaged calculated average velocity (v_{avg}) and estimated average velocity (v_{est}) for each participant along with SD and RMSE.

Proposed method shows deviation from calculated average velocity and is dependent on correctness of measurement of effective length of a leg. On the other hand, in long-term assessment it can be understood as a proportional constant and long-term assessment seeks for deviation from projected average. What is more, the advantage of this method is its simplicity and suitability for implementation directly to wearable sensor's chip. Calculated values tend to be stable over whole dataset and sturdy to small changes of position during the tests.

Table 1: Add a descriptive label of the table here.

No. of participant	Calculated average velocity [m/s]	Estimated average velocity [m/s]	RMSE
1	1,249±0,034	1,106±0,006	0,148
2	1,369±0,075	1,155±0,017	0,223
3	1,210±0,036	1,126±0,028	0,094
4	1,264±0,036	1,176±0,007	0,101

2.3 Methods for hip angle estimation

The main reason for hip angle estimation during walking is the fact that people walking with greater hip extension are more prone to experience anterior hip pain and thus, long-term monitoring of this parameter can provide useful perspective for prevention or treatment. Angle of rotation in any axis can be easily obtained from accelerometer using rotation matrices or from gyroscope by integration of angular velocity. However, these possibilities have some limitations – when using only accelerometer, only roll and pitch angles can be calculated if we assume that yaw axis is aligned with Earth's gravity [12]. On the other hand, gyroscope's power consumption compared to power consumption of accelerometer is much higher and estimated angle is more prone to drifting over longer time periods. For feasibility evaluation of accelerometer for such task, we compared angles roll and pitch, computed from accelerometer's and gyroscope's data, according to (3) and (4) for each axis respectively. Comparison of values is shown on Fig. 4.

$$\text{roll} = \text{atan} \left(\frac{a_y}{\sqrt{a_x^2 + a_z^2}} \right) \quad (3)$$

$$\text{roll} = \int_{t_1}^{t_2} \omega_{\text{roll}} dT \quad (4)$$

A result of comparison is that angle values calculated by from gyroscope are significantly different from values obtained from accelerometer values. Cause of it is the fact that when accelerometer is subject of translational movement, such as walking, angle estimation is becoming unstable due to introduced errors.

Fig. 4: Comparison of values

3. Conclusion

Wearable devices are emerging technology that will become important tool for innovation in various application areas and one of them will be healthcare and homecare. In this article, we verified usability of walking speed estimation method that is suitable for implementation into wearable devices with participation of 4 volunteers. Examined method has advantage of simplicity but on the other hand, approaches utilizing machine learning are appearing and are having better performance in terms of accuracy. Along evaluation of walking speed method, assessment of usage of only accelerometer for monitoring hip's extension has been done. Comparison results in declination of accelerometer's suitability for such observations due to its instability introduced by translational movements. However, using proper filtering method along with sensor fusion such as complementary filter can considerably improve accuracy of measurements.

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5. References and Notes

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