Analysis of Accelerometer Signals for Monitoring of Physical Activity – Methods and Application Results

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Introduction

Accelerometry is the most objective and precise technique to assess physical activity level (PAL) patterns in terms of frequency, duration and intensity (Westerterp, Plasqui, 2004; Vuillemin, 2006). Some devices for measuring of PA intensities were developed and are accessible to use for practical and research purposes. In some studies it was shown that even use of uni-axial accelerometer (MTI Actigraph) can provide a valid index of activity across the intensities (Tweedy, Trost, 2005). In some other studies a tri-axial accelerometers was used (Hoos et al., 2003; Karantonis et al., 2006) or biaxial data were collected (Mader et el., 2006).

The aim of the EUREKA project “Mobile Personal ECG Monitor, HEART GUARD” was to develop a new device for monitoring of cardiovascular functioning under daily life conditions and to develop and implement into the system the monitoring of PAL by use of accelerometers and wireless technologies of data transmission. The aim of the present study was: to develop the method designed for analysis of acceleromeric signals and to check up the abilities of developed system for monitoring of physical activity at free living conditions.

Methods

The new device for registration of ECG and accelerometer signals and with the wireless transmission to computer was developed (within the EUREKA Project E3489 “Heart Guard. Mobile Personal ECG Monitor”). The system architecture design includes definition of system components and implementation requirements, specification of requirements for each unit, specification of interactions inside the system including data transfer standards. It consists of wireless ECG and accelerometers signals registration and transmission device, computer and two packages of software. The first software package is intended for on-line analysis of vital signals and the second – for comprehensive off-line analysis of stored data during monitoring.

Ten healthy adult males take part in this study. Subjects wore the device during the performance of activities of various intensities. Activities were divided into three PAL as slow walk, brisk walk and jogging. All activities were performed at stadium and at the forest at cross-country place. Participants of the study performed the tasks at self selected speeds but the purpose of given locomotion was explained. Each locomotor activity followed-up for 180 seconds. The averaged results registered during the third minute of the tasks were taken for the comparison. During this study only a heart rate (HR) for analysis was taken from registered ECG.

In order to evaluate the PAL of investigated person a special new and effective algorithm for so called integrated PAL assessment has been developed. The essence of this algorithm stands upon accumulation of values of all three X, Y, Z acceleratory signals during the set time interval a-b (in our case – 10s) and calculation the mean values of X, Y, Z signals in time interval a-b according to (1):

\[
\begin{align*}
\bar{X} &= \frac{1}{b-a} \int_a^b X \times dt; \\
\bar{Y} &= \frac{1}{b-a} \int_a^b Y \times dt; \\
\bar{Z} &= \frac{1}{b-a} \int_a^b Z \times dt.
\end{align*}
\]

Additionally, in time interval a-b the modules of mean velocity change are also calculated according to (2):
Finally, the physical activity of investigated person is calculated according to (3):

\[ \tilde{f} = \frac{-v}{b-a} \int_{a}^{b} \sqrt{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2} \cdot \mathrm{d}t. \]  

From above presented sample it could be seen that applying of presented algorithm for calculation of integrated physical activity made possibility for a simple assessment the maximal physical activity value of investigated person, as well as detect the phases of moderate physical activity or resting state.

Calculation of power values by data obtained from accelerometer sensors:

Let's have two-dimensional projections of acceleration vectors in time \( t \)

\[ a_x(t)+k_x g_x, \quad a_y(t)+k_y g_y; \]  

where \( a_x \) – x projection of acceleration vector in time \( t \); \( a_y \) – y projection of acceleration vector in time \( t \); \( g_x \) and \( g_y \) – gravitational acceleration in x and y directions; \( k_x \) and \( k_y \) – orientation coefficients (they are constant, if orientation is stable).

Calculations are performed in time interval \( a-b \), equal of 10s, and in this interval the mean values \( \bar{x} \) and \( \bar{y} \) of \( k_x g_x \) and \( k_y g_y \) are determined:

\[ \bar{x} = \frac{1}{b-a} \int_{a}^{b} a_x \cdot \mathrm{d}t; \]  
\[ \bar{y} = \frac{1}{b-a} \int_{a}^{b} a_y \cdot \mathrm{d}t. \]  

Mean value of velocity model in the interval \( a-b \) is defined by

\[ \bar{v} = \frac{1}{b-a} \int_{a}^{b} \sqrt{(ax-x)^2 + (ay-y)^2} \cdot \mathrm{d}t; \]  

Mean value of power \( \tilde{f} \), proportional to work in fixed time interval \( a-b \) is defined by

\[ \tilde{f} = \frac{-v}{b-a} \int_{a}^{b} \sqrt{(ax-x)^2 + (ay-y)^2} \cdot \mathrm{d}t; \]  

The obtained value \( \tilde{f} \) is normalized with regard to converter coefficient, sampling rate and body mass of investigated person.

\[ a = k \cdot \frac{m \cdot \tilde{f}}{h}; \]  

where \( k = 1/3200 \) – converter coefficient, \( m \) – body mass of investigated [kg], \( h \) – sampling rate 500 [Hz].

```c
float integral(short *ax, short *ay, short len){
    int j, w, wx, wy, sx=0, sy=0, v=0;
    float f=0.0;
    for(j=len;--j>=0;){ // find
        sx+=ax[j]; // x mean
        sy+=ay[j]; // y mean
        for(sx<len, sy<len, j<len;--j){
            wx=(ax[j]-sx)/32; // 1 g = 100 sensitivity
            wy=(ay[j]-sy)/32; // 32  – converter
            w=sqrt(wx*wx+wy*wy); // module of instantaneous
            // acceleration
            v=v+w; // mean velocity
            f=f+w*v; // mean work (power, if time is fixed)
        }
        return f/(len*500)/100; // normalization 500Hz sampling
        // rate,
        // by sensitivity of sensor (100).
    }
}
```

Fig. 1. Algorithm implemented in C++ software

An algorithm was realized in presented below program which was created by means of C++ programming language tools (Fig. 1).

Results and Discussion

Fig. 2 presents the final document presented on the screen of computer showing dynamics of integrated PAL while performing one of the locomotor tasks. The values of heart rate and increase in registered values of integral PAL during the various intensities of locomotion are presented in the Table 1.

Analysis of changes in HR during the performance of locomotion of various intensities shoved that the same physical task requires a different energy costs in dependence on the environmental conditions. Cross-country conditions, i.e. mountain and more twists required the more mobilization of cardiovascular system as to perform the task and the bigger changes in HR was observed. If during the jogging at the stadium HR was 138.2±4.4 b/min. during the performance of the same task at cross-country conditions was 149.6±4.7 b/min. (difference between these values was significant, \( p<0.05 \)).

![Fig. 2. Final document presented on the screen of computer showing dynamics of integrated PAL](image-url)
It was showed that a combination of HR and accelerometry as well as ACC alone has potential as a method for assessment of energy expenditure during free-living activities (Kumahara et al., 2006). There no doubt concerning the understanding the data obtained during this study which complements plentiful number of such studies.

Table 1. Values of heart rate (HR) and increase in values of normalized integral PAL level registered during the various intensities of locomotion (Mean±SD)

<table>
<thead>
<tr>
<th>Venue of experiment</th>
<th>Locomotion</th>
<th>HR, b/min</th>
<th>Level of PA, Relative Power, W/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadium</td>
<td>Slow walk</td>
<td>89.6 ±4.1</td>
<td>1.52±0.09</td>
</tr>
<tr>
<td></td>
<td>Brisk walk</td>
<td>126.4 ±4.2</td>
<td>1.72±0.07</td>
</tr>
<tr>
<td></td>
<td>Jogging</td>
<td>138.2 ±4.4</td>
<td>1.89±0.15</td>
</tr>
<tr>
<td>Cross-country</td>
<td>Slow walk</td>
<td>96.4 ±5.9</td>
<td>1.68±0.12</td>
</tr>
<tr>
<td></td>
<td>Brisk walk</td>
<td>137.1 ±4.4</td>
<td>1.84±0.16</td>
</tr>
<tr>
<td></td>
<td>Jogging</td>
<td>149.6 ±4.7</td>
<td>1.89±0.17</td>
</tr>
</tbody>
</table>

Owing to the negative effects that insufficient PA may have impact on health, the interest in methods to measure PAL increases (Franks, 2006; Lima, Glaner, 2006). The present study was aimed to assess the PA pattern in daily living conditions. Our data confirms the conclusions of others (Westerterp, Plasqui, 2004; Sunami et al., 2006; Vuillemin, 2006) that accelerometry is the objective and suitable technique for assessment of PA patterns.

Conclusion

The developed algorithm upon accumulation of values of all three X, Y, Z acceleratory signals allows to identify physical activity level across the various intensities investigated under free-living conditions.

Acknowledgements

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References

9. Sunami Y., Shiami Y., Okishima K., Nishimura M., Yoshitake Y., Adachi M. Validity of uniaxial accelerometer estimating tge energy expenditure of walking and running in early childhood // 11th Annual Congress of the
The aim was to present the developed system designed for monitoring of physical activity and analysis of accelerometric signals and present the results of applications of the system while various locomotions performed. The participants after warm-up at stadium and at cross-country conditions when the locomotion compounds more turns, swings and other unexpected movements. Ill. 2, bibl. 12 (in English; summaries in English, Russian and Lithuanian).

The results of the study showed that such analysis allowed to define and distinguish allowed to identify physical activity levels across the various intensities investigated at the stadium and at the cross-country conditions when the locomotion compounds more turns, swings and other unexpected movements. Ill. 2, bibl. 12 (in English; summaries in English, Russian and Lithuanian).