ELECTRONCS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2009. No. 6(94)
ELEKTRONIKA IR ELEKTROTECHNIKA

MEDICINE TECHNOLOGY
T 115
MEDICINOS TECHNOLOGIJA

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

J. Poderys, A. Buliuolis, A. Grunovas
Laboratory of Kinesiology, Lithuanian Academy of Physical Education,
Ausros str. 42–31, LT–44221, Kaunas, Lithuania, phone: +370 37 302650, e-mail: l.poderys@lkka.lt.
A. Vainoras, R. Ruseckas
Institute of Cardiology, Kaunas Universty of Medicine,
Sukileliu av. 17, LT–3007, Kaunas, Lithuania, phone + 370 687 92521, e-mail: alfonsas.vainoras@med.kmu.lt.

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 E!3489 "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 froe 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):

$$\begin{cases} \overline{X} = \dfrac{1}{b-a}\displaystyle\int_a^b X \times dt\,; \\ \overline{Y} = \dfrac{1}{b-a}\displaystyle\int_a^b Y \times dt\,; \\ \overline{Z} = \dfrac{1}{b-a}\displaystyle\int_a^b Z \times dt. \end{cases} \quad (1)$$

Additionally, in time interval a-b the modules of mean velocity change are also calculated according to (2):

$$\bar{v} = \frac{1}{b-a} \int_a^b \sqrt{\left(X - \bar{X}\right)^2 + \left(Y - \bar{Y}\right)^2 + \left(Z - \bar{Z}\right)^2} \cdot dt \,. \qquad (2)$$

Finally, the physical activity of investigated person is calculated according to (3):

$$\bar{f} = \frac{\bar{v}}{b-a} \int_a^b \sqrt{\left(X - \bar{X}\right)^2 + \left(Y - \bar{Y}\right)^2 + \left(Z - \bar{Z}\right)^2} \cdot dt \,. \qquad (3)$$

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 accelerator sensors:

let's have two-dimensional projections of acceleration vectors in time t

$$a_x(t)+k_x g_x, \qquad a_y(t)+k_y g_y; \qquad (4)$$

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:

$$\bar{x} = \frac{1}{b-a} \int_a^b ax \cdot dt; \qquad (5)$$

$$\bar{y} = \frac{1}{b-a} \int_a^b ay \cdot dt. \qquad (6)$$

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

$$\bar{v} = \frac{1}{b-a} \int_a^b \sqrt{(ax - \bar{x})^2 + (ay - \bar{y})^2} \cdot dt; \qquad (7)$$

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

$$\bar{f} = \frac{\bar{v}}{b-a} \int_a^b \sqrt{(ax - \bar{x})^2 + (ay - \bar{y})^2} \cdot dt; \qquad (8)$$

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

$$a = k \cdot \frac{m \cdot \bar{f}}{h}; \qquad (9)$$

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

```
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>=0;){
      wx=((ax[j]-sx)/32);       // 1 g = 100 sensitivity
                                // of sensor
      wy=((ay[j]-sy)/32);       // 32  - converter
                                // coefficient
      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*).

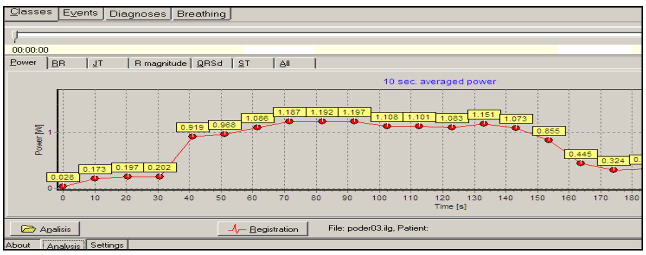

Fig. 2. Final document presented on the screen of computer showing dynamics of integrated PAL

There was proposed a lot of methods for assessment of energy expenditure during free living conditions, such as monitoring of HR, or physical activity level measured by doubly labelled water method and accelerometry, accelerometry combined with HR telemetry, portable global positioning units in complement with accelerometry (Hoos et al., 2003; Kumahara et al., 2004; Rodriguez et al., 2005). 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*)

Venue of experiment	**Locomotion**	**HR,** *b/min*	**Level of PA,** *Relative Power, W/kg*
Stadium	*Slow walk*	89.6 ±4.1	1.52±0.09
	Brisk walk	126.4,3 ±4.5	1.71±0.12
	Jogging	138.2 ±4.4	1.89±0.15
Cross-country	*Slow walk*	96.4 ±4.6	1.66±0.12
	Brisk walk	137.1 ±4.4	1.84±0.16
	Jogging	149.6 ±4.7	1.89±0.17

Analysis or the integrated PAL results obtained during the study showed that the developed system allowed to identify PA across the various intensities investigated at the stadium and at the cross-country conditions. There was no found a statistically significant difference between the integrated PAL during the slow walk at stadium and at cross-country conditions when analysis of PAL was performed of vertical movements only. But if the analysis of movements were performed by use the data obtained from all directions of the trunk (*anteroposterior, mediolateral and vertical*) the difference became statistically significant ($p<0,05$). Comparison of the increases in PAL during the brisk walk and during the jogging at cross-country conditions obtained by accelerometry confirmed the same point – it allows identifying PAL across the various intensities.

There was proposed many of methods for assessment of PA level or energy expenditure during free living conditions, such as monitoring of HR, or PA level measured by doubly labeled water and accelerometry, accelerometry combined with HR telemetry, portable global positioning units in complement with accelerometry (Hoos et al., 2003; Kumahara et al., 2004; Rodriguez et al., 2005). It was showed that a combination of HR and accelerometry as well as accelerometry alone has potential as a method for assessment of energy expenditure during free-living activities (Kumahara et al., 2004; Karantonis et al., 2006). In developed ECG and motion activity monitoring system, proposed decision algorithm based on the convolution of Moore and Mealy automata (Berskiene et all, 2005) and created two packages of software on-line and off-line data analysis was implemented. The real time software for personal monitor is created by using plain C^{++} and can run on different PC platforms.

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

The study was supported by a grant from the Agency for International Science and Technology Development Programs in Lithuania within the EUREKA Project E!3489 "Heart Guard. Mobile Personal ECG Monitor".

References

1. **Berskiene K., Aseriskyte D., Navickas Z., Vainoras A.** Development of Information System for E – health using Mealy and Moore automata // Mathematics and mathematical modelling. – Kaunas: Technologija, 2005. – No. 1. – P. 48–54.
2. **Franks P. V.** A gene-lifestyle interaction perspective // 11th Annual Congress of the European College of Sport Science. Book of Abstracts. – 2006. – P. 455.
3. **Hoos M. B., Plasqui G., Gerver W. J., Westerterp K. R.** Physical activity level measured by doubly labeled water and accelerometry in children // Eur. J. Appl. Physiol. – 2003. – Vol. 89, No. 6. – P. 624–626.
4. **Karantonis D. M., Narayanan M. R., Mathie M., Lovell N. H., Celler B. G.** Implementation of a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring // IEEE Trans Inf Technol Biomed. – 2006. – Vol. 10, No. 1. – P. 156–167.
5. **Kumahara H., Schutz Y., Ayabe M., Yoshioka M., Yoshitake Y., Shindo M., Ishii K., Tanaka H.** The use of uniaxial accelerometry for the assessment of physical-activity-related energy expenditure: a validation study against whole-body indirect calorimetry // British Journal of Nutrition. – 2004. – Vol. 91, No. 2. – P. 235–243.
6. **Lima W. A., Glaner M. F.** Differentation of the risk factors in agreement with the level of physical activity // 11th Annual Congress of the European College of Sport Science. Book of Abstracts. – 2006. – P. 592.
7. **Mader U., Ruch N., Rumo M., Martin B.W.** Clasification of physical activity by heart rate and accelerometry data, recorded simultaneously // 11th Annual Congress of the European College of Sport Science. Book of Abstracts. – 2006. – P. 345.
8. **Rodriguez D. A., Brown A. L., Troped P. J.** Portable global positioning units to complement accelerometry-based physical activity monitors // Med. Sci. Sports. Exerc. – 2005. – Vol. 37, No. 11 (Suppl.). – P. 572–581.
9. **Sunami Y., Shiami Y., Okishima K., Nshimuta M., Yoshitake Y., Adachi M.** Validity of unuiaxial accelerometry estimating tge energy expenditure of walking and running in early childhood // 11th Annual Congress of the

European College of Sport Science. Book of Abstracts. – 2006. – P. 544.
10. **Tweedy S. M., Trost S. G.** Validity of accelerometry for measurement of activity in people with brain injury // Med. Sci. Sports Exerc. – 2005. – Vol. 37, No. 9. – P. 1474–1480.
11. **Vuillemin A.** How to assess physical activity in elderly? // 11th Annual Congress of the European College of Sport Science. Book of Abstracts. – 2006. – P. 439.
12. **Westerterp K. R., Plasqui G.** Physical activity and human energy expenditure // Curr. Opin. Clin. Nutr. Metab. Care. – 2004. – Vol. 7, No. 6. – P. 607–613

Received 2009 02 13

J. Poderys, A. Buliuolis, A. Grunovas, A. Vainoras, R. Ruseckas. Analysis of Accelerometer Signals for Monitoring of Physical Activity – Methods and Application Results // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 85–88.

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 loco motions performed. The participants after warm-up at stadium and at cross-country place performed three tasks i.e. slow walk, brisk walk and jogging. The accelerometers measurements and calculation of integrated acceleration curves from the anteroposterior, mediolateral and vertical directions was an indicator of physical activity level. 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).

И. Подерис, А. Булюолис, А. Груновас, А. Ваинорас, Р. Русецкас. Анализ сигналов датчиков ускорения с целью мониторинга физической активности – метод и резултаты применения // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – C. 85–88.

Представлена новая разработанная система для наблюдения физической активности, оценивая двигательную активность по сигналам датчиков ускорительния и представлены результаты исследований разработанного обарудования. Испытуемые после разминки на дорожке стадиона или на местности выполняли по три двигательные задания: 1 – медленная ходьба; 2 – скоростная ходьба; 3 – бег трусцой. Оценивая ускорения движений тела при различной интенсивности физической активности было анализированно интегрированные кривые ускорения отдельно на вертикальной осси и всех трех оссях интегрированные кривые ускорения. Результаты исследований показали, что регистрация и анализ кривых полученных от датчиков ускорения позволяет определить интенсивность физической активности и чётко оценить особенности движения тела в натуральных условиях, когда испытуемый двигаясь по пересеченной местности выполняет много поворотов и других непридвиденных движений. Ил. 2, библ. 12. (на английском языке; рефераты на английском, русском и литовском яз.).

J. Poderys, A. Buliuolis., A. Grunovas, A. Vainoras, R. Ruseckas. Pagreičio jutiklio signalų analizė ilgalaikės fizinio aktyvumo stebėsenos tikslu – metodika ir taikymo rezultatai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94) . – P. 85–88.

Pristatyta nauja fizinio aktyvumo stebėsenos sistema, judėjimo aktyvumą vertinanti pagal pagreičio jutiklių registruojamus signalus ir pateikti sukurtos įrangos bandymų rezultatai. Tiriamieji po mankštos stadiono takelyje ir raižytoje vietovėje atliko po tris judėjimo užduotis: 1 – lėtas ėjimas; 2 – spartus ėjimas; 3 – bėgimas ristele. Vertinant kūno judėjimo pagreičius, esant įvairiam fizinio aktyvumo intensyvumui, buvo analizuojamos integruotos pagreičio kreivės atskirai vertikalioje ašyje ir visų trijų ašių integruotos pagreičio kreivės. Gauti tyrimo rezultatai parodė, kad pagreičio kreivių registravimas ir analizė leidžia atpažinti tirtus fizinio aktyvumo intensyvumus ir tiksliai įvertintina kūno judėjimo ypatybes natūraliose sąlygose kai tiriamasis judėdamas raižyta ir atlieka daug posūkių ir kitų nenumatytų judesių. Il. 2, bibl. 12 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).