Recognition of Daily Ambulatory Movements utilizing Accelerometer and Barometer

7 authors, including:


Yasuaki Ohtaki
Kanagawa Institute of Technology

Hikaru Inooka
Tohoku University


Koichi Sagawa
Hirosaki University


Xiumin Zhang
Jilin University

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RECOGNITION OF DAILY AMBULATORY MOVEMENTS UTILIZING ACCELEROMETER AND BAROMETER

Yasuaki Ohtaki, Hikaru Inooka
New Industry Creation Hatchery Center
Tohoku University
04 Aoba, Aoba-ku
Sendai 980-8579, JAPAN
Email: ohtaki@hsq.niche.tohoku.ac.jp

Koichi Sagawa
Faculty of Science and Technology
Hirosaki University
3 Bunkyo-cho, Hirosaki
Aomori 036-8561, JAPAN

Akihiro Suzuki
Instruments Technology Research Co. Ltd.
2-1-40 Takamori, Izumi-ku
Sendai 981-3203, JAPAN

Zhan Xiumin, Mitsuharu Okutsu,
and Ryoichi Nagatomi
Graduate School of Medicine
Tohoku University
2-1 Seiryou, Aoba-ku
Sendai 980-8575, JAPAN

ABSTRACT
Main objective of this study is to evaluate physical activity by means of a portable device that estimates the type of physical activity and the exercise intensity. A simple and effective algorithm was proposed to classify physical activities including vertical movements, such as stair climbing or use of elevator. A portable measurement device with accelerometers and a barometer was specially designed to detect the features of vertical movements. Walking speed was calculated by an equation which estimates the walking speed as a function of signal energy of vertical body acceleration during walking. Healthy young subjects participated in our experimental study. The portable device was attached to the waist. To confirm the feasibility of the method, oxygen uptake was also measured by a portable expiratory gas analyzer. Experimental results showed that the proposed method classified all type of ambulatory defined in the algorithm successfully. Resultant energy consumption estimated by the proposed method was found to be similar to the measured values of the expiratory gas analyzer. It was suggested that the consideration of vertical movements made a improvement in the estimation of energy consumptions, and the proposed method provides better estimation of physical activity.

KEY WORDS
Ergonomics systems, Portable instruments, Quality of life, Physical activity, Energy expenditure, Human walking

1 Introduction

Physical activity is an essential factor of quality of life. Currently, the amount of energy consumption due to daily physical activity is widely accepted as an important factor in the prevention of obesity, diabetes, hyperlipidemia, cardiovascular disease, and muscle wasting in the aged people. A practical and reliable method to investigate individual's daily physical activity allows better assessment, such as of outcomes of medical interventions. Information such as intensity of exercise, types of activities is also necessary to appropriately formulate safe and beneficial exercise program on individual basis[1]. Ambulatory movement is the friendliest exercise easy to perform that does not require any special equipment. Therefore, a reliable assessment of ambulatory movements in daily life, such as walking, climbing stairs up and down, is preferable for the exercise prescription in clinics as well as in health promotion programs.

A variety of methods have been used to quantify daily energy expenditure in a more precise manner by means of heart rate monitoring, oxygen uptake measurement or doubly labeled water. However, these methods are cumbersome or impractical in recording daily energy expenditure of free living people. In order to overcome those shortcomings, various advanced small calorie counters were developed utilizing accelerometers or angular velocity sensors attaching to the waist, wrist or ankle[2][3][4][5][6]. Many studies have demonstrated the usefulness of accelerometry for the evaluation of physical activity, mostly focusing on the detection of level walking or active/rest discrimination. However, with regard to the vertical movement such as stair climbing, the evaluation of energy consumption has been still insufficient even though stair climbing requires more than twice the energy of level walking[7]. This is because of difficulties in the detection of vertical movement. The type of exercise and its intensity are determinant factors of the energy consumption[8][9]. Therefore, a precise evaluation of energy expenditure requires further detailed classification of ambulatory movements. The walking speed also contributes to the energy consumption, though it is still difficult to estimate accurately under unconstrained daily environments from acceleration data.

Main objective of this study is to present a simple and practical method to recognize detailed ambulatory movements, both indoors and outdoors in daily life. Special attention was paid to the classification of vertical movements and the walking speed estimation. Potential usefulness of the proposed method was investigated in comparison with portable expiratory gas measurement.

2 Method

2.1 Portable device

We have developed a portable measurement device (*Intelligent Calorie Counter: ICC*), as shown in Figure 1. The device consisted of IC accelerometers (AnalogDevices, ADXL202E, ± 2 [G]) with 16-bit duty cycle converter, a packaged silicon piezoresistive pressure sensor (Fujikura, X3AM-115KPASR), Li-Ionic batteries, micro processor units and flash memory. This equipment is small ($85 \times 45 \times 18.5$ [mm]) and light enough to carry without any restriction. The equipment was designed to be attached on the waist. Signals were sampled at 33 [Hz]. Data were downloaded via USB, and processed offline by PC.

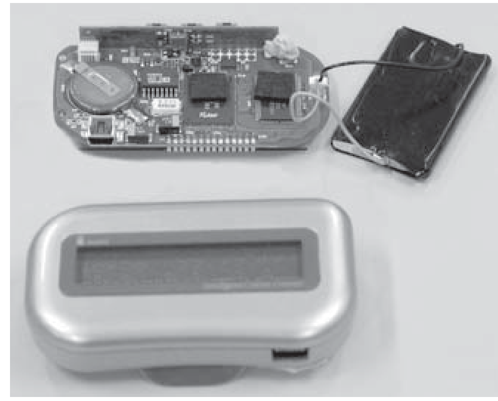

Figure 1. Portable measurement device (ICC) with embedded electronics. Examainators or subjects can check the status of measurement by LCD.

2.2 Estimation of gait factors

The body acceleration reflects characteristics of the biped locomotion. An accelerometer is preferable to detect frequency and intensity of vibrational motion. The walking periodicity (cadence) appeared as a frequency peek in a spectrum as shown in Figure 2. Therefore, the walking activity was identified by a condition with a variance over 0.02 [G] and frequency peak inside 1-3 [Hz] in the spectrum. It was postulated that the walking speed reflects both the strength and the frequency of pelvis vibration during normal level walking[10]. The signal energy of pelvis vibration in the walking frequency bandwidth 1-3 [Hz] was considered as a determinant of one's natural walking speed. Relationships among the signal energy, step length, and walking speed were investigated. An estimate equation of walking speed as a function of signal energy was formulated from the accelerometry of 199 subjects including young and elderly people.

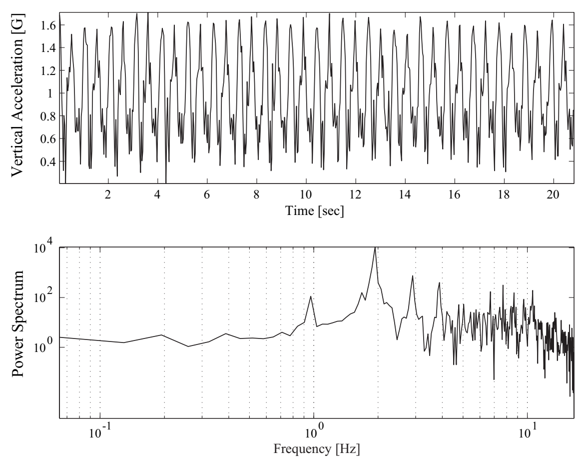

Figure 2. An example of vertical acceleration and power spectrum during normal level walking. Accelerometer was attached to the waist.

2.3 Detection of vertical movements

In order to classify ambulatory movements including vertical position shifts, a practical methods was developed to detect slight altitude changes by use of a barometer. Direct measurement of the air pressure or its differential hardly gives precise altitudes change, because of the effect of weather conditions, artifacts, and high frequency measurement noise. Weather conditions sometimes cause larger air pressure changes than that of the vertical altitude change caused by one's motion. However, the change in the atmospheric pressure due to weather changes appears to be much slower than that caused by one's motion. On the other hand, air pressure differentials practically indicate vertical position shifts. Considering the above points, a Kalman filter with low-pass characteristics was designed to eliminate effects of such disturbances and to get optimal estimation of the air pressure differential. A value of air pressure differential corresponds to a direction and speed of the vertical movements. The value of 1 [Pa/s] correspond to vertical position shift of 8.49 [cm/s].

2.4 Classification of activities

Clustering approach provides classification of six activities as level walking, climbing up/down stairs, going up/down in an elevator, and rest (static). Feature vectors consisted of the signal energy of the vertical acceleration and the air pressure differential were formulated to distinguish each activity. An appropriate discriminant function was designed to classify the feature vector of each movement, considering Maharanobis' generalized distance. The categorie "Others" were identified when any of the six activities were distant from the uncertain feature vector. Reference data of the discriminant function were experimentally collected by preliminary investigations of six kinds of elevators (lifting speed: 58.9 - 101.5 [m/min]) and four kinds of stairs (inclination pitch: 3.5 - 30.0 [deg.]) with twenty-two young normal subject. In the classification algorithm, short term movements that change less than three seconds were negligible to assess main series of ambulatory movements. The algorithm made about five seconds delay for classification, which would be negligible in the evaluation of energy expenditure.

2.5 Estimation of energy consumption

Total energy consumption is the summation of the individual's basic metabolism and the energy consumption by exercise. The basic metabolism can be calculated by the basal metabolic rate (BMR) and the resting duration. The basal metabolic rate is the number of calories burned in a day while lying down, which depends on one's age and gender. On the other hand, the energy consumption during the exercise depends on its intensity [kcal/min/kg], duration, and body weight. Considering that the most of daily activities consists of many short term exercises, conventional use of the relative metabolic rate (RMR) or the metabolic equivalents (METs) would not be appropriate which assumes long term exercises. Then, new regressive models were established to predict short term energy expenditure in daily activity, considering post-exercise oxygen consumption (EPOC). Oxygen uptake ($\dot{V}O2$) of three minutes walking and maximum sixty step stair walking in several speeds were investigated by a portable expiratory gas analyzer (AT1100, Anima Co., Tokyo Japan) in breath-by-breath mode. Then, an estimate equation as a function of activity type and walking speed were formulated.

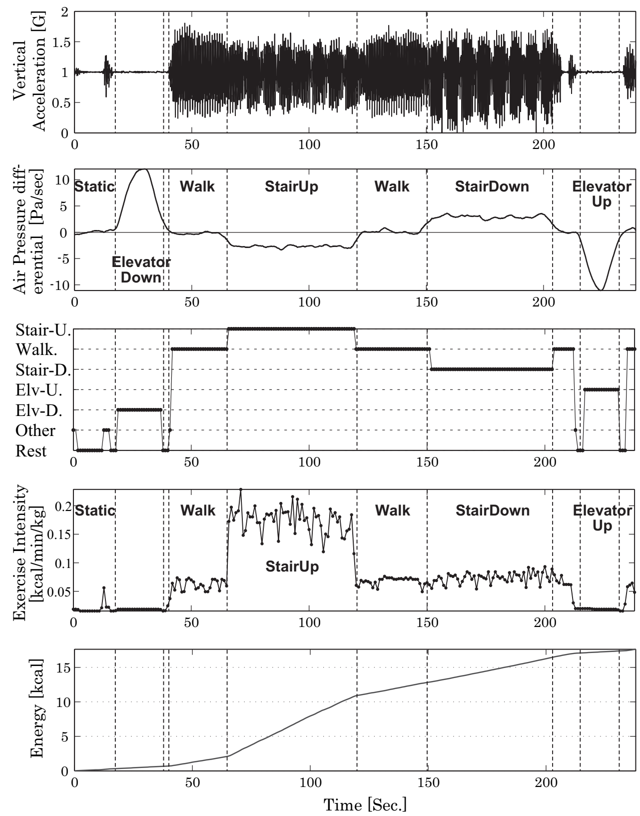

Figure 3. Typical waveform of vertical accelerations, air pressure differentials, classification results, estimated exercise intensity, and energy consumtion in the first experiment. Notation U. and D. indicate 'going up'and 'going down' respectively.

3 Experiments and Results

Prior to the testing session, each subject read and signed an informed consent form. The first experiment was designed to show the usefulness of the method to identify and classify details of ambulatory movements. Subjects were thirteen young volunteers (Age: 23.9 ± 2.02). The portable device ICC was attached on the waist of subject. Video recording was performed to note true activity change. Sampling frequency was 33 [Hz]. Subjects were instructed to move in the sequence of "static standing → going down in an elevator → walking through level corridor → climbing up stairs → walking → climbing down stairs → walking → going up in an elevator".

Typical result was shown in Figure 3. Top three graphs of Figure 3 illustrate vertical acceleration, air pressure differentials, and classification results. Broken line indicates the true activity change timing that delayed five second. The series of ambulatory movements were accurately classified in all the subjects and the trials. Short walking of in and out of the elevator cage was detectable just before and after the use of elevator. Irregular upper body movements were observed sometimes in the standing posture, which were classified to "Other". Bottom two graphs of Figure 3 illustrate estimated exercise intensity, and estimated energy consumptions. Note that exercise intensity of the vertical movements was reasonably evaluated.

The second experiment was performed to validate and evaluate accuracy of the energy consumption estimation. Oxygen uptake was measured in the condition of sequential movement as "three minutes static standing → tree minutes walking → sixty steps stair climbing up → sixty steps stair down". Three young male (Age: 26 ± 3) participated in the experiment. ICC was attached to the waist. Results were shown in Table 1. Energy consumption estimated by the proposed method was found to be similar to the measured values of the expiratory analyzer, both in total, rest, and exercise terms. Results showed that the estimated energy consumption was tolerably acculate to assess physical activity.

Table 1. Accuracy of energy consumption estimated by ICC. Error is represented as mean value of absolute difference with standard deviation given in parenthesis.

Method	Energy Consumption.Mean(SD)[kcal]		
	Total	Rest	Exercise
ICC	32.72(2.74)	3.86(0.30)	28.85(2.47)
Expiratory	31.65(2.03)	3.52(0.26)	28.12(1.85)
Error	1.07(1.10)	0.34(0.18)	0.73(0.93)

4 Conclusion

In this article, a method to evaluate energy expenditure of ambulatory movements was described. A small portable device (ICC) utilizing an accelerometers and a barometer was developed, which detects features of ambulatory movements considering vertical position shifts. The classification method based on a frequency analysis of body acceleration and data processing of air pressure variation provided identification and classification of one's ambulatory movements without spacial limitations and restrictions. Furthermore, walking speed was estimated from the signal energy of the body acceleration. Experimental results have shown that the proposed method is able to effectively classify and evaluate level walking, stair climbing, and elevator use. Resultant energy consumption estimated by the proposed method was found to be similar to the measured values of the expiratory gas analyzer. The proposed method would provide better estimation of energy expenditure and exercise intensity as compared to conventional pedometer based calorie counters. Further application of the present technique may be helpful in the health promotion of both young and elderly, and in the management of obese, diabetic, hyperlipidemic and cardiac patients.

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