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An Wearable Energy Expenditure Analysis System based on the 15-channel Whole-body Segment Acceleration Measurement

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Abstract—**The measurement of the amount of energy utilized during physical activity has generated considerable interests from various groups ranging from exercise physiologists to nutritionists and fitness center workers. To date, however, the existing energy expenditure estimation methods are not so reliable and compact. In this paper, we propose a new method for accurately and easily estimating energy expenditure during physical activity with a novel algorithm. This method involves acquiring acceleration signals through a 15-channel whole-body segment acceleration measurement system and then estimating the calories expended using a newly developed algorithm. The results of 3 subjects' experiments were compared with a commercially available mask type indirect calorimeter and a 9-axis accelerometry-based calorimeter. The results demonstrate that the proposed method provides a new and reliable way to estimate human energy expenditure during physical activity.**

Keywords—**energy expenditure estimation, 15-channel whole-body segment acceleration measurement system, mask type indirect calorimeter, 9-axis accelerometry-based calorimeter**

I. INTRODUCTION

Nowadays, the percentage of obese people in the general population has been increasing significantly as have many complications associated with obesity. For this reason, preventing people from becoming overweight is one of the most effective way to live a healthy life. Based on a simple truth that overweight is a result of imbalance between intake and expenditure of energy, it is very important to have reliable and valid monitoring of the amount of energy expended [1]. Accurate and direct measurement, however, is impossible because human metabolism and body dynamics are very complicated. Thus, the direct measurement of energy expenditure(EE) during physical activity has been a methodological challenge and various alternative methods have been devised. Among these methods, the most accurate method based on the measurement of doubly labled water [2] requires a longer time to obtain results and the cost is prohibitively high.

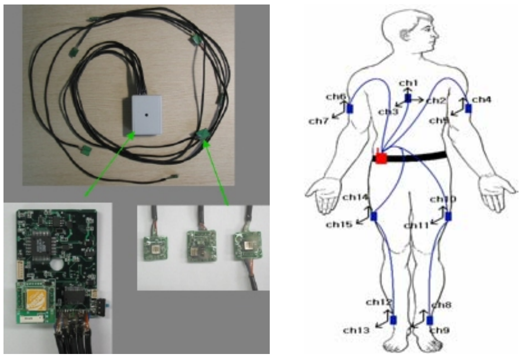
Indirect methods such as diet records [3] and activity questionnaires [4] are unreliable due to factors such as recall bias. Other measurement devices such as heart rate monitors [5] and pedometer [6] have considerable limitations.

In order to provide wearability of the device, we focused on using accelerometers to capture EE information. In this study, a new system called whole-body segment acceleration measurement system(WBSAMS), was developed for EE estimation. The developed system differs from previous systems in a couple of aspects. First, using the WBSAMS, one can conveniently measure the total 7 whole-body segments acceleration including the arm, which improves overall estimation accuracy. Second, we does not use a fitting algorithm nor simply count the peak of acceleration signals to calculate the amount of energy utilized [7]. Rather, the proposed system utilizes a novel algorithm that can estimate an intact calorie unit.

II. MATERIALS AND METHODS

1) Experiment

The acceleration signals of subject's body segments were generated from 2-axis accelerometer sensors (ADXL210E, Analog Devices, USA), and the signals were wirelessly acquired in real-time by a Bluetooth® module (Promi SD, Initium, Korea). The developed hardware system is shown in Fig.1 (a) and the subjects, who wear the system as shown in Fig.1 (b), can freely walk or run for various speed. Acceleration signals were transferred to a PC through a Bluetooth® module and then the newly developed algorithm calculated energy expenditure incalorie units. The three subjects were healthy men in their 20's with heights and weights of 174cm/54kg, 180cm/71kg, 169cm/71kg each. The estimation results were compared with two other reference devices: a) a mask type gas analyzer(k4b^2, Cosmed, Itary) which is an indirect calorimeter, and b) a 9-axis accelerometry-based calorimeter (IDEEA, MiniSun, USA).



(a) (b)

Fig.1. Pictures of (a) the WBSAMS, and (b) the appearance of an equipped subject.

All subjects were equipped with the three devices simultaneously and walked or ran on a treadmill for 10 minutes period at 7 different speed set. The measured acceleration data is transferred to a PC using a Bluetooth® module, and then converted into expended energy in calories.

2) Algorithm

The idea that expended energy can be calculated from an acceleration signal starts with a concept shown in Fig.2. The acceleration signal is integrated to be converted into velocity, and from this, the kinetic energy (KE) is calculated from a simple physics equation, ***KE = 1/2 mv²***. Figure 3 represents the proposed algorithm. The algorithm shows that KE is determined from the acceleration signals and assumes that the difference of ***KE(n+1)*** and ***KE(n)*** is ***W(n)***, the amount of energy that the subject worked.

Firstly, the acceleration signal is filtered with a low and a high pass filter, and integrated to produce the velocity signal. The kinetic energy of the body is calculated by ***KE=1/2 mv²*** and then |***KE(n+1)-KE(n)***| is referred to ***w(n)*** as the work given to the body. Finally, the summation of work performed, **Σ*W(n)***, is determined as the total energy expenditure during physical activity.

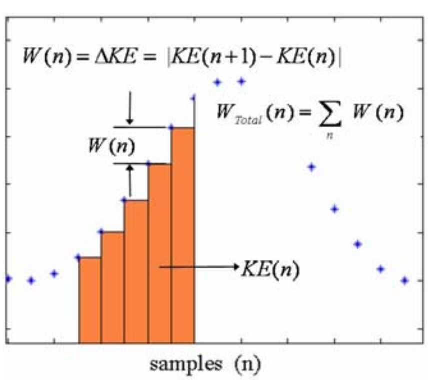


Fig.2. Illustration of the relationship between work and energy.

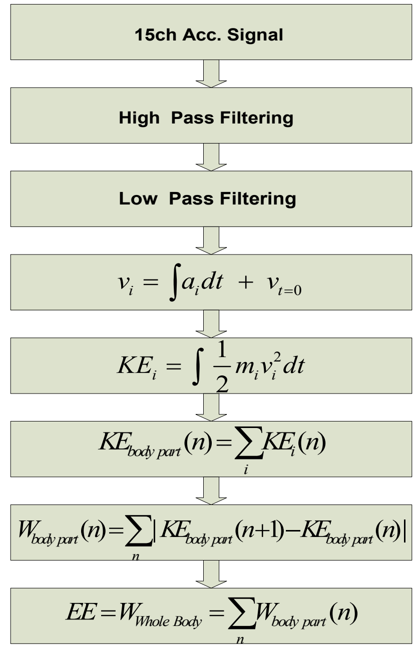


Fig.3. Algorithm of EE estimation.

III. Results

The EE estimation results of the proposed method are compared with two commercially available devices. Fig. 4 shows a typical result for one test subjects out of total 3 subjects' experiment. In this figure, the horizontal axis represents the intensity of activity (running speed on a treadmill, km/h) and the vertical axis represents the estimated energy expenditure in kcal Each point corresponds to the 10-minute walking or running with the given speed.

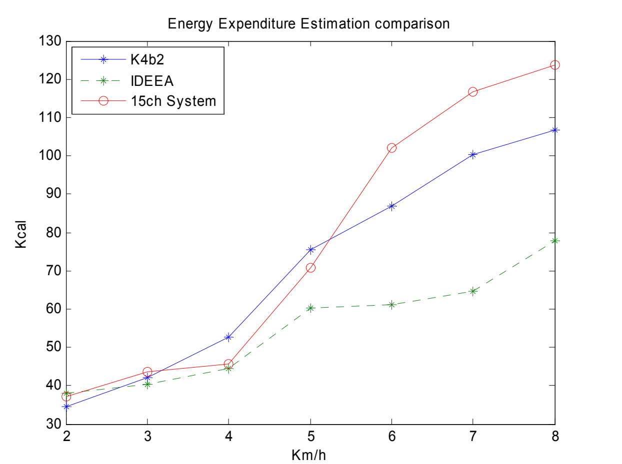


Fig.4. Graph of the three results. 15ch System line (blue) is the result of WBSAMS.

Figure 4 reveals that the result of the proposed method using the WBSAMS is similar to that of gas analyzer type indirect calorimeter(K4b^2) although IDEEA and WBSAMS both obtained raw data signals from accelerometers. There exists an noticeable difference in calculated amount of total calories expended between two accelerometer-based methods as the speed on the treadmill was increased. As the results shows, total calories used for activity was proportional to the intensity of the activity, and correlation coefficient of the results from the 3 subjects were r=0.9571 (p=0.0027), r=0.9818 (p=0.0001), and r=0.9019 (p=0.0140).

IV. Discussion & Conclusions

Several groups have tried to calculate EE during physical activity, however until now none of these methods has been accepted as a highly accurate and reliable method. Recently, many studies have attempted to use accelerometer due to its more compactness and simplicity, but it lacks in accurateness of measurements. That is the reason why K4b^2 is considered to be much more accurate than IDEEA. Our study concludes that performance of the developed method based on the WBSAMS are closer to K4b^2 than to IDEEA. This experiment gave 3 subjects' results, r=0.9571 (p=0.0027), r=0.9818 (p=0.0001), r=0.9019 (p=0.0140), each. Additionally, we have provided a possible explanation for why IDEEA consistently underestimates EE when compared with K4b^2: IDEEA lacks arm acceleration input.

In the future, experiments on a larger scale of test subjects are essential for acquiring more reliable results. It is our goal to develop a totally wearable EE analysis system for a wider population of people to use more accurately as well as more conveniently.

V. Acknowledgement

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VI. References

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