Estimation of energy expenditure using PVDF vibration sensor and 3-axis accelerometer

Chansong Hwang[1] , Youngchul Lim[1], Jaejoong Im[1] , Soowan Chae[2,3,4], Baikhwan Cho[5], Eunkyung Choi[2], Jiyoung Yang[3], Eunock Park[2]

[1] Division of Electronic Engineering, Chonbuk National University, Jeonju, Korea
[2]Clinical Trial Center for Functional Foods, Chonbuk National University Hospital, Jeonju, Republic of Korea
[3]Clinical Trial Center, Chonbuk National University Hospital, Jeonju, Republic of Korea
[4]Department of Pharmacology, Chonbuk National University, Medical School, Jeonju, Republic of Korea,
[5]Department of Medical Nutrition Therapy,, Chonbuk National University Hospital, Jeonju, Republic of Korea

Abstract. Body consumes energy not only by body activities but also by voices such as talking and singing, however, current devices calculate energy expenditure values based on body activities only. This study was performed to estimate energy consumption caused by voice as well as body movement using PVDF vibration sensor and 3-axis accelerometer, respectively. Twenty six subjects were participated under the experimental condition of reading book, singing, walking and running on the treadmill with the use of developed sensing module and respiratory gas analyzer. Parameters extracted from the voice signal and accelerometer outputs were compared with the actual energy consumption obtained from gas analyzer. R^2 values of voice signal and body activity signal were found to be 0.669 and 0.691, respectively.

Keywords: energy expenditure, 3-axis accelerometer, PVDF vibration sensor, voice, gas analyzer

1 Introduction

With increasing interests in healthcare, various devices including energy expenditure measurement have been used to manage obesity in normal daily life. Almost all of those devices mainly acquire body activity information, and provide estimated energy expenditure values [1-2]. Such devices utilize 3-axis accelerometer, pedometer, infrared sensor, pressure sensor, and GPS chip as sensors for the extraction of parameters to be used for the correlation study [3-5]. However, such devices overlooked all of the possible environments on energy consumption. For example, we spend about 39kcal for the duration of 30 minutes of talking, laughing, and phone conversation [6]. That is, the device for the estimation of energy expenditure should include the analysis of voice signals.

In this study, energy expenditure measurement module, which includes 3-axis accelerometer and PVDF vibration sensor, was developed to estimate energy expenditure caused not only by activity but also by voice. Actual data were acquired under various experimental conditions with the use of developed sensing module and gas analyzer. Regression equation for estimating energy expenditure was established by finding correlation between activity/voice signal obtained from the sensing module and actual energy expenditure obtained from respiratory gas analyzer.

2 Methods

Sensing module including 3-axis accelerometer and PVDF(polyvinylidene fluoride) film was fabricated to acquire activity and voice signal. PVDF film was used to obtain voice signal transmitted through the bone at the sternum. While wearing sensing module on the chest, gas analyzer was used to obtain actual energy consumption during waking/running on the treadmill and reading/singing. Once data were acquired from the subjects, regression analysis was performed to establish relationship among acquired data.

Twenty six subjects (12 men and 14 women, 19 to 29 years old) with normal body mass indices were participated for data collection. Data acquisition was performed using activity and voice detection module and the respiratory gas analyzer (Vmax Encore 29). First of all, basal metabolic rate was obtained under resting condition for 30 minutes before data collection.

Data collection for voice signal was performed for two minutes under the condition of reading book and singing. Then, two minutes were provided for resting. Once the respiratory exchange rate becomes normal, another trial was performed, and each condition was repeated three times. Data collection for body activity was performed under the condition of walking and running. Each step includes one minute of warming up, data acquisition of three minutes, cool down of one minute, and three minutes of resting.

Power values from the voice signal were extracted for each experimental condition. Acquired data were divided into every 40 seconds of data set, and the averaged values of integrated voice signals for each set were calculated. SVM (Signal Vector Magnitude) values were extracted for activity signals obtained from 3-axis accelerometer. Activity data were also divided into every 40 seconds of data set, and the averaged values of integrated signals for each set were calculated.

3 Results and Discussion

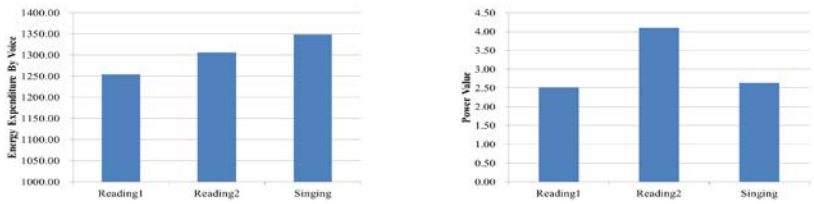
Power values extracted from voice signals were averaged for three different experimental conditions, reading 1, reading 2, and singing. Fig. 1(a) shows the actual energy expenditure values obtained from respiratory gas analyzer, and Fig. 1(b) shows the power values obtained from voice signals.

As can be seen from the figure, actual energy consumption increased for each experimental condition in the order of reading 1, reading 2, and singing. However, the power values reveal the highest values for the condition of reading book 2, and the power values for singing show almost same values with the reading 1 condition. It implies that talking or singing definitely increases the energy consumption, however, the vibration sensor output provides only increment of voice signal amplitude, which may not directly related to the energy consumption. Therefore, it is necessary to extract additional parameters from the voice signals which could indicate the level of breathing amount.

Multiple regression analysis was performed to find the relationship between actual energy consumption as dependent variable and voice signal parameters and resting energy expenditures as independent variables. Since the power values from voice signal does not show high correlation, BMI(body mass index) and REE(resting energy expenditure) were also included as independent variables for the regression analysis. Based on the regression analysis results, R^2 value was found to be 0.669, and the multiple regression equation was established as follows.

Energy expenditure by voice(kcal)

$$= -1647.896 + 13.064(\text{power value}) + 80.508(\text{BMI}) + 1.025(\text{REE})$$

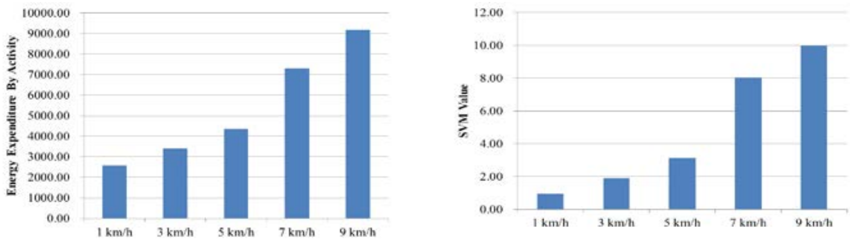


(a) (b)

Fig. 1. Averaged actual energy expenditures (a) and power values from vibration sensor output (b) while reading book and singing.

Fig. 2(a) shows the averaged actual energy expenditure values obtained from respiratory gas analyzer while walking and running. It was obvious that energy consumption was increased steadily as the speed of treadmill increases. Fig. 2(b) represents the change of SVM values out of 3-axis accelerometer, and it also reveals that the parameter values increase with the same pattern as actual energy expenditure.

Multiple regression analysis was performed to find the relationship between actual energy consumption as dependent variable and SVM value as independent variable. R^2 value was found to be 0.691, and the multiple regression equation was established as Energy expenditure as activity (kcal) equals 2149.974 + 652.425(SVM value).



(a) (b)

Fig. 2. Averaged actual energy expenditures (a) and SVM values from 3-axis accelerometer output (b) while walking and running.

5 Conclusions

The study was performed to find the relationship between actual energy expenditure and physiological signals. Energy expenditure sensing module, which includes 3-axis accelerometer and PVDF vibration sensor, was developed in house. In addition to the sensing module, respiratory gas analyzer was used for the measurement of actual energy consumption during various experimental conditions. Multiple regression analysis was performed and regression equation was established for the estimation of energy consumed during various conditions.

Power values were extracted from voice signals under the experimental conditions, reading 1, reading 2, and singing. SVM values were extracted from body activity signals under the treadmill speed from 1km/hour to 9km/hour. It was obvious that the actual energy consumption was increased for each experimental condition both for voice signals and for body activity signals. However, the power values from voice signal did not show consistent increment of the values, and it was probably caused by reading book or singing without enough respiration.

This study was performed with the subjects of 20-25 years old healthy collegiate students with normal BMI values, and it should be extended for the large group of cohort study for more accurate estimation of energy expenditure. Large number of data and various parameter extraction would provide more reliable regression equation for the estimation of energy expenditure, which could be applied to the daily use.

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