Acquisition of Voice Signal using PVDF Vibration Sensor for Finding Relationship between Voices and Energy Expenditure

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Abstract

Portable devices for providing energy expenditure information have been developed in the area of u-healthcare environment. The 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 voices using PVDF vibration sensor. Sensing module for acquiring voice transmitted through bone, placed on the sternum area, was fabricated in house. Twenty six subjects were participated for the experiment for data collection while reading book and singing with the use of respiratory gas analyzer. Also, body movement was acquired using 3-axis accelerometer while walking and running on the treadmill with the use of gas analyzer, too. Parameters extracted from the voice signal and accelerometer outputs were compared with the actual energy consumption obtained from gas analyzer for finding linear regression equation. R-square values of voice signal and body activity signal were found to be 0.669 and 0.691, respectively, and the regression equations were established accordingly.

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

1. Introduction

With increasing interest in healthcare, exercising population for the management and protection of health is gradually increasing. Among the various methods for health management, energy expenditure measurement devices have been used to help management of obesity in normal daily life. Almost all of those devices mainly acquire body activity information using 3-axis accelerometer, and provide estimated energy expenditure values [1-4]. Those studies acquire only body activities, and find the correlation between body activities and actual energy consumption. Such devices utilize pedometer, infrared sensor, pressure sensor, and GPS chip as sensors for the extraction of parameters to be used for the correlation study [5-9]. However, such devices using accelerometers for estimating energy expenditure do not include all possible environments on energy consumption. We fill hungry after talking or singing, which implies that energies are consumed. For example, we spend about 39Kcal for the duration of 30 minutes of talking, laughing, and phone conversation [10]. That is, the device for the estimation of energy expenditure should include the analysis of voice signals.

However, it is impossible to obtain voice signal using acoustic microphone during daily life. Therefore, it calls for the development of sensing module which acquire voice signal without disturbing of normal activities. Moreover, the sensor has to collect only the user's voice signal without disturbance of ambient noises. PVDF (polyvinylidene fluoride) film could be used for acquiring voice signal conducted from trachea through bone [11], and the vibration could be obtained from sternum area on the chest.

In this study, energy expenditure measurement module, which includes PVDF vibration sensor and 3-axis accelerometer [12], 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

2.1. Experimental Design

Sensing module including 3-axis accelerometer, PVDF(polyvinylidene fluoride) film, and analog filters was fabricated to acquire activity and voice signal. PVDF film was used to obtain voice signal at the sternum on the chest transmitted though bone. While wearing sensing module on the chest, gas analyzer was also used to obtain actual energy consumption during walking/running on the treadmill and reading/singing. Once data were acquired from the subjects, regression analysis was performed to establish relationship among acquired data. Figure 1 shows an overall experimental design for the study.

2.2. PVDF vibration sensor

2.2.1 Sensor development: For the detection of voice signal, vibration sensor (Figure 2) was designed using PVDF film and impedance matching circuits. Sensor output has the frequency response of 5Hz～5kHz as shown in figure 3. Once the user generates the voice signal, it transmits through bone from trachea, and the signal could be acquired from sternum on the chest or on the back.

2.2.2 Sensor location: PVDF sensor was used for the detection of vibration caused by voice signal transmitted through bone. Data collection was performed to find the best location (either chest or back) for the placement of the sensor. Figure 4(a) and Figure 4(b) represent the waveforms obtained from the chest and the back, respectively. As can be seen from the figures, sensor on the back gives lower signal amplitude than that from the chest, and it is inconvenient wearing sensing module on the back. Therefore, sternum area on the chest was selected for the measurement of voice signals.

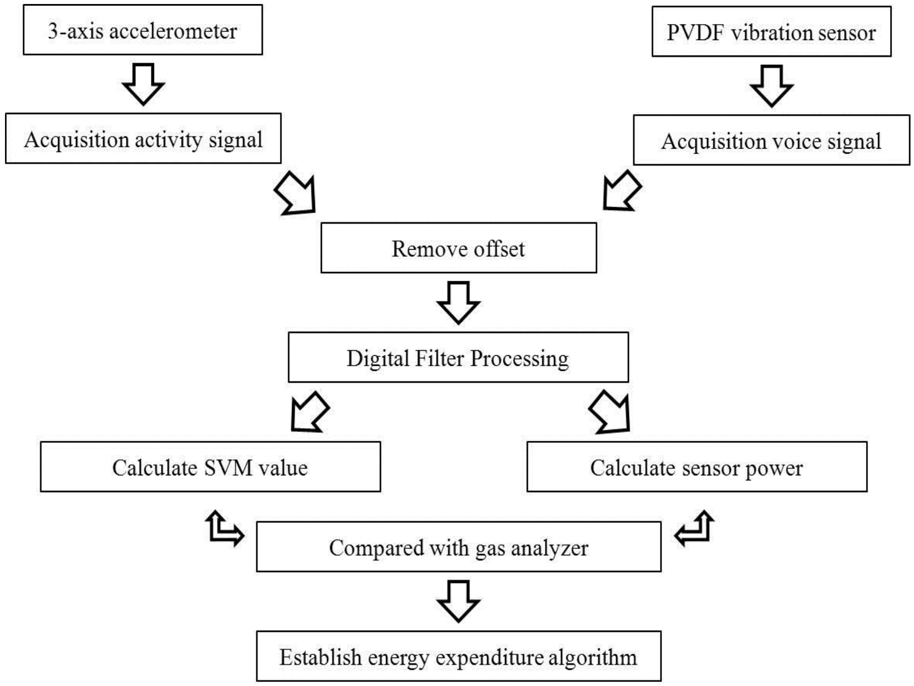


Figure 1. Overall experimental design for data collection and analysis

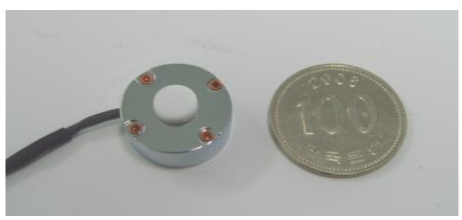


Figure 2. Picture of the PVDF vibration sensor

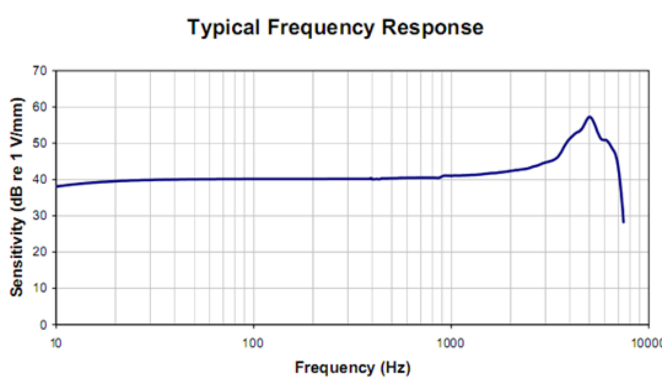
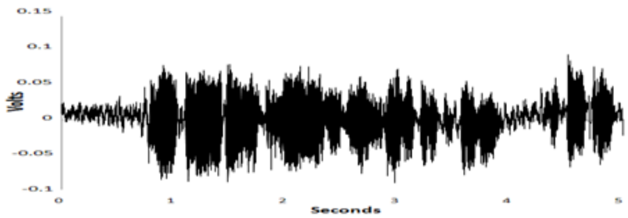
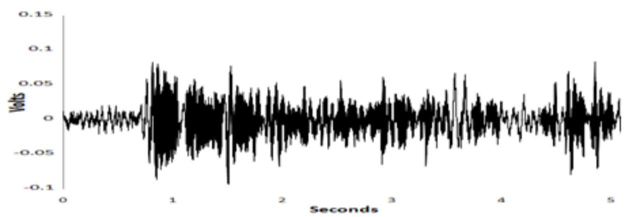


Figure 3. Typical frequency response of PVDF sensor



(a) voice signal on the sternum area on the chest



(b) voice signal from the back

Figure 4. Voice signals obtained from the chest and the back

2.3. Data Acquisition and Analysis

Twenty six healthy subjects (12 men and 14 women) with the age of 19 to 29 years old were participated for data collection. Subjects were chosen who have normal BMI (body mass index), and they were examined for congenital or chronic diseases. Data acquisition was performed using activity and voice detection module and the respiratory gas analyzer. MP-150(BIOPAC, USA) was used for data collection with the sampling rate of 500Hz. Actual energy expenditure were obtained using gas analyzer (Vmax Encore 29). Basal metabolic rate was obtained under resting condition for 30 minutes using gas analyzer. Subjects were asked to fast for at least 12 hours before the experiment.

Data collection for voice signal was performed under the condition of reading book and singing under the normal VO_2 and VCO_2 level. Data acquisition was performed for 2 minutes, and then 2 minutes was provided for rest. 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 (1km/hour, 3km/hour, 5km/hour) and running (7km/hour, 9km/hour). Each experimental step includes 1 minute of warming up, data acquisition of 3 minutes, cool down of 1 minute, and 3 minutes of resting. Data collection was performed only while VO_2 and VCO_2 level shows normal values.

Figure 5 represents the raw data from PVDF sensor while reading the book and Figure 6 represents the signal after performing the signal processing.

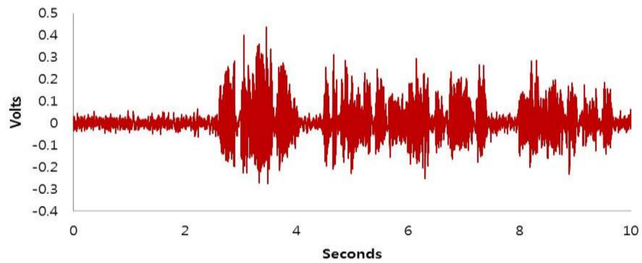


Figure 5. Raw voice signal during reading book

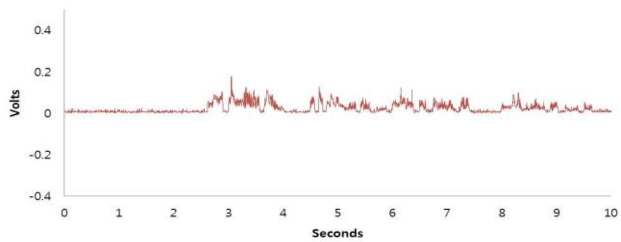


Figure 6. Voice signal after filtering, rectification, and smoothing

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 from 3-axis accelerometer output were extracted as activity parameters. 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

3.1. Voice signals

Voice signals obtained from PVDF vibration sensor were processed for parameter extraction. Power values extracted from voice signals out of 26 subjects were averaged for three different experimental conditions, reading 1, reading 2, and singing. Figure 7 shows the actual energy expenditure values obtained from respiratory gas analyzer, and Figure 8 shows the power values obtained from voice signals.

As can be seen from the figures, actual energy consumption for each experimental condition increased for each experimental condition in the order of reading 1, reading 2, and singing. However, the power values revealed the highest values for the condition of reading book 2, and the power values for singing showed 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 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) was also included as independent variable for the regression analysis. Multiple regression analysis results are summarized in Table 1.

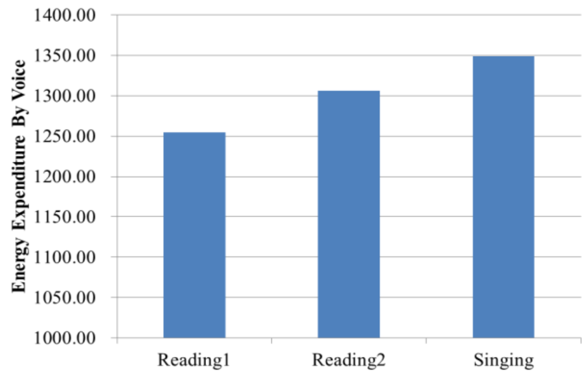


Figure 7. Averaged actual energy expenditures while reading book and singing

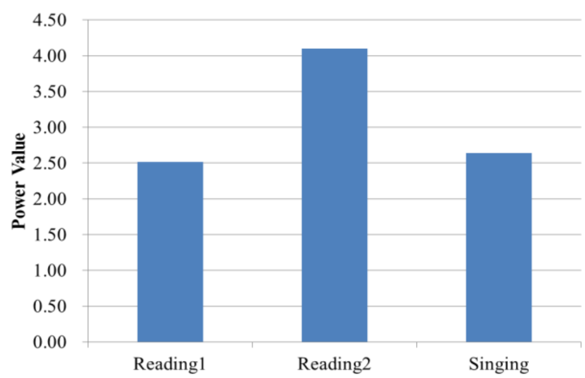


Figure 8. Averaged power values from the vibration sensor output while reading book and singing

Table 1. Summary of multiple regression analysis results between actual energy consumption and voice signal parameters

classification	Std.Error	Sig.
Power values from vibration sensor	5.109	0.011
Body mass index (BMI)	10.831	0.000
Resting energy expenditure (REE)	0.073	0.000

Based on the regression analysis results, R-square value was found to be 0.669, and the multiple regression equation was established as follows.

$$\text{Energy expenditure by voice(kcal)} = -1647.896 + 13.064(\text{power value}) + 80.508(\text{BMI}) + 1.025(\text{REE})$$

3.2. Activity signals

Figure 9 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. Figure 10 represents the change of SVM values out of 3-axis accelerometer, and it also revealed that the parameter values increase with the same pattern as actual energy expenditure changes.

Multiple regression analysis was performed to find the relationship between actual energy consumption as dependent variable and SVM value as independent variable, and the results are summarized in Table 2. Based on the regression analysis results, R2 value was found to be 0.691, and the multiple regression equation was established as

$$\text{Energy expenditure by activity(kcal)} = 2149.974 + 652.425(\text{SVM value})$$

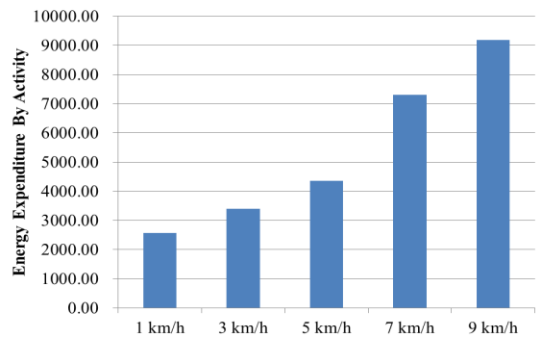


Figure 9. Averaged actual energy expenditures while walking and running

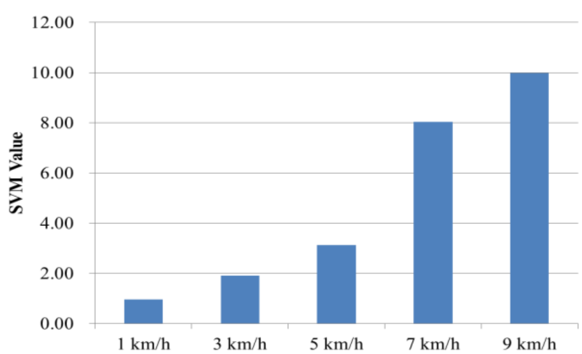


Figure 10. Averaged SVM values from 3-axis accelerometer output while walking and running

Table 2. Summary of multiple regression analysis results between actual energy consumption and SVM values from body activity

classification	Std.Error	Sig.
SVM value of accelerometer	38.562	0.000

4. 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 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 daily lives.

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 for each experimental condition increased for each experimental condition either for voice signals or 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.

Multiple regression analysis results showed the R-square values of around 0.6, which are not high enough for the correlation. However, it provides the possibility of using voice signal for the estimation of energy expenditure. Moreover, the results could be used for the training of vocal experts which requires 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 to the various cohort study for more accurate estimation of energy expenditure. Once the study is proceeded with large number of data and various parameter extraction, more reliable regression equation could be established.

References

[1] S. E. Crouter, J. R. Churilla and D. R. Bassett, “Estimating energy expenditure using accelerometers”, Eur. J. Appl. Physiol., vol. 98, **(2006)**, pp. 601-612 .
[2] R. Maddison, Y. Jiang, S. V. Hoom, C. N. Mhurchu, C. M. M. Lawes, A. Rodgers and E. Rush, “Estimating Energy Expenditure With the RT3 Triaxial Accelerometer”, Research Quarterly for Exercise and Sport, vol. 80, no. 2, **(2009)**, pp. 249-256.
[3] C. V. C. Bouten, K. T. M. Koekkoek, M. Verduin, R. Kodde, J. D. Janssen, A Triaxial Accelerometer and Portable Data Processing Unit for the Assessment of Daily Physical Activity, IEEE Trans. Biomed., **(1997)**, Vol. 44(3), pp.136-147.
[4] Y. M. Song, H. J. Ku, M. C. Lee and S. B. Lee, “Methods of Estimation of Physical Activity and Energy Expenditure”, International Journal of Coaching Science, vol. 7, no. 3, **(2005)**, pp.159-168.
[5] C. F. Randal, M. L. Lorraine, M. Chinmay, K. M. Shelly, R. K. Kenton, J. P. Denny and A. L. James, “Precision and accuracy of an ankle-worn accelerometer-based pedometer in step counting and energy expenditure”, Preventive Medicine, vol. 41, **(2005)**, pp.778-783.
[6] M. H. Lee, H. K. Lee, K. W. Choi, S. K. Bang, J. W. Kim and S. R. Kim, (Eds.), “Method of Measuring Calorie Consumption for Portable Apparatus”, Engineering in Medicine and Biology 27th Annual Conference, **(2005)**, pp. 5203-5206.
[7] P. Juha, E. Miikka, K. Panu, M. Jani, P. Johannes and K. IIkka, “Acivity Classification Using Realistic Data Form Wearable Sensors”, IEEE Trans. Biomed. , vol. 10, no. 1, **(2006)**, pp. 119-128.
[8] S. S. Edward, F. George, H. James, S. Yves and B. Raymond, “Monitoring of Posture Allocations and Activities by a Shoe-Based Wearable Sensor”, IEEE Trans. Biomed., vol. 58, no. 4, **(2011)**, pp. 983-990.
[9] Z. L. Sun, X. C. Mao, W. F. Tian and X. F. Zhang, “Acivity classification and dead reckoning for pedestrian navigation with wearable sensors”, Meas. Sci. Technol., vol. 20, **(2009)**, pp. 1-10.
[10] B. H. Kang, (Ed.), “Well-being diet diary”, The Beautiful Society, **(2005)**.
[11] D. K. Jee, R. Wei, H. S. Kim and J. J. Im, “Snoring Detection using Polyvinylidene Fluoride Vibration Sensors”, Korean Journal of the Science or Emotion & Sensibility, vol. 14, no. 3, **(2011)**, pp. 459-466.
[12] J. J. Im and Y. C. Lim, “Electronic Stethoscope using PVDF Sensor for Wireless Transmission of Heart and Lung Sounds”, JIWIT, vol. 12, no. 6, **(2012)**, pp. 57-63.

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