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Master's Degree Thesis

A Study of Wireless Patch Type Sensor Module for Estimating the Energy Expenditure

Graduate School of Chosun University

Department of IT Fusion Technology
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This thesis is submitted to Chosun University in partial fulfillment of the requirements for a Master's degree

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master's degree in IT Fusion Technology.

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ABSTRACT

A Study of Wireless Patch Type Sensor Module for Estimating the Energy Expenditure

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For ubiquitous healthcare system, in-situ monitoring of energy expenditure is one of essential requirement. Ubiquitous healthcare means monitoring anyone, in everywhere without any dependence on time and location. Excess nutrient and energy imbalance are considered major important cause of chronic disease. Either of them is base on the individual energy consumption and caloric intake.

In this thesis, accurate quantification of physical activity energy expenditure has been evaluated by the wireless patch type sensor module. The combined heart rate and movement sensors method is used for measuring energy expenditure against indirect calorimetry Cosmed $K4b^2$ (Cosmed, Srl, Italy). The sensing module for the heart rate (HR), movement index (MI) detection, is proposed to assess physical activity in populations. For the desired correlation equations between physical activity and energy expenditure; heart rate, movement data measured from Bruce protocol test on the treadmill (0~15Km/h). The experiment results verify that the chest patched type wireless sensor module AirBeat system has strong relationship with oxygen consumption (R^2=0.78). However the wireless HR-MI sensor overestimated energy expenditure during low activities and underestimated the energy during the intensive activities ($p<0.001$).

요약

신체 활동 에너지 측정을 위한 부착형 센서 모듈 연구

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유비쿼터스 헬스케어 시스템에서 에너지 소비량의 실시간 모니터링은 필수 요구사항 중 하나이다. 유비쿼터스 헬스케어는 시간과 장소에 구애됨이 없이 어디서든, 어떤 사람에게라도 신체 정보의 모니터링이 가능함을 의미한다. 과다한 영양분과 에너지 불균형은 고질적인 질병의 매우 중요한 원인으로 고려된다. 이 두 가지 요소는 독립적인 에너지 소비량과 칼로리 섭취량에 기초로 두고 있다.

이 논문에서 물리적인 활동에너지 소비량의 정확한 양은 무선 패치 형태의 센서 모듈에 의해 측정된다. 센서모듈에 내장된 심박수와 움직임 센서는 간접적인 열량 측정법 Cosmed K4b^2 (Cosmed, Srl, Italy)에 의한 에너지 소비량 측정을 위해 사용되었다. 인체의 물리적 활동 감지를 위해 심박수와 움직임 지수(MI)를 측정하였다. 물리적인 활동과 에너지 소비량 사이의 상관 관계식은 심박수와 트레드밀(0~15Km/h)에 관한 Bruce 프로토콜 테스트로부터 추정하였다. 실험 결과 가슴 부착형 형태의 무선 센서 모듈인 AirBeat 시스템은 산소 소비(R^2=0.78)와 밀접한 상관관계가 있음이 증명 되었다. 그러나 무선 HR-MI 센서는 작은 움직임 동안 에너지 소비량이 높게 측정 되었고, 격렬한 움직임에서의 에너지 소비는 실제보다 낮게($p<0.001$) 측정 되었다.

Table of Contents

List of Tables

List of Figures

Acronyms

ECG:	Electrocardiography
EE:	Energy Expenditure
BMR:	Basal Metabolic Rate
DIT:	Diet Induced Thermogenesis
PPT:	Post Prandial Thermogenesis
EI:	Energy Intake
TEF:	Thermic Effect of Food
PA:	Physical Activity
RMR:	Rest Metabolic Rate
VO_2:	O_2 Consumption
VCO_2:	CO_2 Production
HR:	Hear Rate
MI	Movement Index
SD	Standard Deviation
BMI	Body Mass Index
MCU	Microprogrammed Control Unit

I. Introduction

A. Definition of energy and energy expenditure

1. Energy

Humans oxidise (metabolism) carbohydrate, protein, fat (and alcohol) to produce energy. The energy is needed:
- To maintain body functions - to breathe, to keep the heart beating, to keep the body warm and all the other functions that keep the body alive
- The body warm and all the other functions that keep the body alive
- For physical activity - for active movement - muscle contraction
- For growth and repair, which require new tissues to be made.

2. Energy Expenditure

The amount of energy used to perform an activity. A baseline of energy is used to maintain life functions.

The energy expenditure (EE) of a man or woman over a whole day is often divided into different components, which can be individually determined [2]. These are (Figure 1.1):

a) Basal Metabolic Rate (BMR)

The basal metabolic rate is defined as the basal metabolism of an animal. BMR is the minimal rate of energy expenditure compatible with life. In other words, it is the minimum amount of energy (expressed in number of calories) our body needs to stay alive at rest [31]. For the basal metabolic rate estimation to be accurate, several assumptions must be true at the time of measurement:

- Absence of gross muscular activity - i.e. you MUST be resting, and your muscles must be relaxed.
- Post-absorptive state - i.e. 12 hours or more after the last meal.
- Thermal neutrality - i.e. ambient temperature variations should be minimal (not too hot or cold).
- Emotional disturbance must be minimal, as studies have shown that emotional upset, particularly apprehension, may result in rises in BMR of from 15–40 percent awake state, as sleep tends to depress BMR by approximately 10 percent.

b) Diet Induced Thermogenesis (DIT)

Also called post-prandial thermogenesis (PPT) or the thermic effect of food (TEF). DIT accounts for about 10% of total energy intake (EI) for a mixed western diet. This is the amount of energy utilized in the digestion, absorption and transportation of nutrients.

c) Physical Activity (PA)

PA is the most variable component of EE in humans. It includes the additional EE above RMR and TEF due to muscular activity and comprises minor physical movement (such as shivering and fidgeting) as well as purposeful gross muscular work or physical exercise. In this study, we focus on the physical activity measurement.

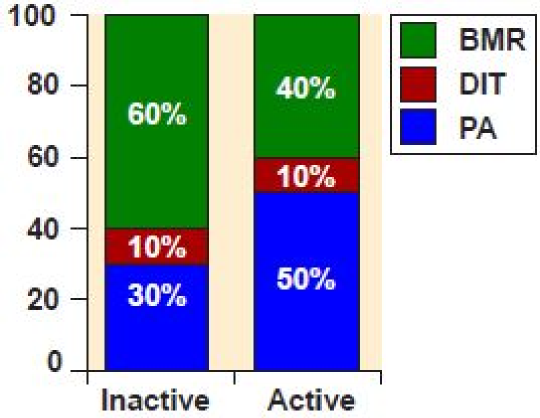

Figure 1.1 Total energy expenditure.

The three primary source of energy for human body as follows:

Glucose: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (1)

Fats: $C_{16}H_{32}O_2 + 23O_2 \rightarrow 16CO_2 + 16H_2O$ (2)

Proteins: $C_{72}H_{112}N_2O_{22}S + 77O_2 \rightarrow 63CO_2 + 38H_2O + SO_3 + 9CO(NH_2)_2$ (3)

From the equation, we can measure the oxygen consumption or dioxide oxygen production for indirectly estimating energy expenditure. To convert the amount of oxygen consumed into heat equivalents, one must know the type of energy substrate that is being metabolized, that is, carbohydrate or fat, since protein rarely participates in energy metabolism. The energy liberated when fat is the only substrate being oxidized is 4.7 kcal or 19.7 kJ per liter of oxygen used. However, the energy released when carbohydrate is the only fuel being oxidized is 5.05 kcal or 21.1 kJ per liter of oxygen used. Another measure often implemented, although it is less accurate, estimates the energy expenditure of exercise on the basis of 5 kcal or 21 kJ per liter of oxygen used. Therefore, a person exercising at an oxygen consumption of 2.0 L · min^{-1} would expend approximately 10 kcal or 42 kJ of energy per minute. Consequently, the use of an energy equivalent of 4.825 kcal per liter of oxygen has been suggested for circumstances such as resting or steady-state exercise at mild intensities.

B. Research Necessity

Recently, the rate of chronic disease such as obesity, hypertension, and diabetic is rapidly increased. Excess nutrient and energy imbalance are considered major important cause of chronic disease. Either of them is base on the individual energy consumption and caloric intake. Energy is needed to power muscular activity but that excessive energy storage can lead to obesity and other metabolic disorders, it is important to understand what energy transformation is all about, how energy expenditure can be assessed and quantified, and what strategies either can augment energy provision to enhance performance or can maximize energy utilization to facilitate weight loss or maintain optimal body weight. Simply explained as the following Figure 1.2:

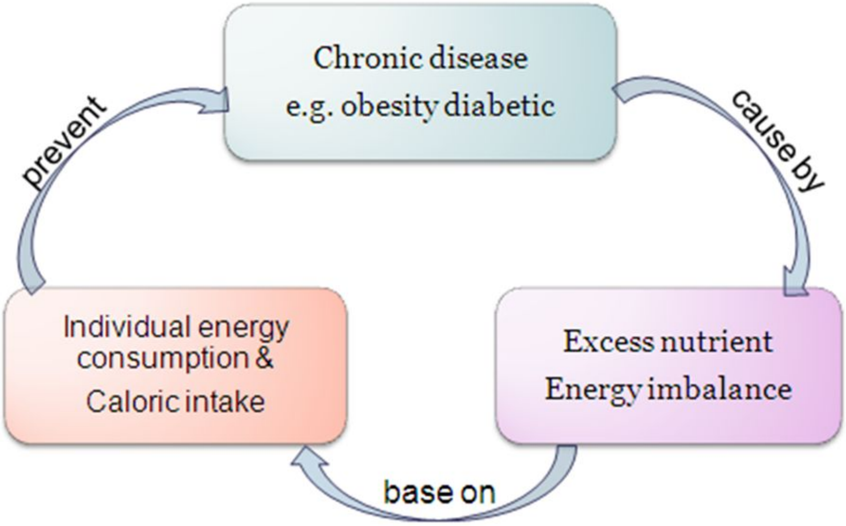

Figure 1.2 Necessity for measuring human energy expenditure.

C. Research Final Target

For estimating energy expenditure, already have a range of methods. Researchers used variety of sensors and algorithms to estimate energy expenditure. However the accuracy of estimation is difficult. The high accuracy always depend on laboratory. The cumbersome devices are not comfortable to wear and also need physician to help. The researchers focus on light weight, small size and high accuracy to estimate the energy expenditure.

In this thesis, we used a small size, light weight patch type sensor module (AirBeat System) to realize the basic physical activity energy expenditure estimation on the treadmill. The final target:

- To associate with multiple sensors into relatively homeogenous, small size, long power duration one.

- Develop software for a sophisticated in determining energy expenditure and can record data for a long time.
- Realize accuracy energy expenditure estimation from lab to free-living.

D. Thesis Organization

Chapter Ⅰ introduces the basic background knowledge and the principle of indirect energy expenditure estimation. Explained why we do this research and what's the final target for this study. Chapter Ⅱ presents the common methods for estimating energy expenditure and discusses the problem and limitation of each method. Chapter Ⅲ shows our method and the experiment process how to estimate energy expenditure. Chapter Ⅳ demonstrates the accuracy results. This thesis is concluded in the last chapter.

II. Methods for Estimating Energy Expenditure

A range of methods are used in the assessment of energy expenditure. These major methods maybe be classified in to direct calorimetry, indirect calorimetry, heart rate monitoring, movement sensors, and combined heart rate and movement sensors. This chapter lists the methods with their advantage and problems.

A. Direct Calorimetry

1. Definition

The process of measuring heat production occurred via both cellular respiration and cell work in an animal is called direct calorimetry.

2. Method

Using a thermally-isolated chamber, the heat subjects dissipated by evaporation, radiation, conduction and convection is recorded accurately and measured precisely. In direct calorimetry, on the other hand, CO_2 production and O_2 consumption are measured [30]. Assuming that all the oxygen is used to oxidize degradable fuels and all the CO_2 there by evolved is recovered, it is possible to calculate the total amount of energy produced.

To measure this heat, a person is placed in a specially designed, insulated chamber (called a calorimeter) supplied with air and surrounded by a jacket of circulating water; the heat production (or energy expenditure) is estimated from changes in the temperature of the surrounding water (Figure 2.1).

$$Q = cm\Delta T \qquad (4)$$

Where Q is the heat energy put into or taken out of the substance, m is the mass of the substance, c is the specific heat capacity, and ΔT is the change in temperature [1].

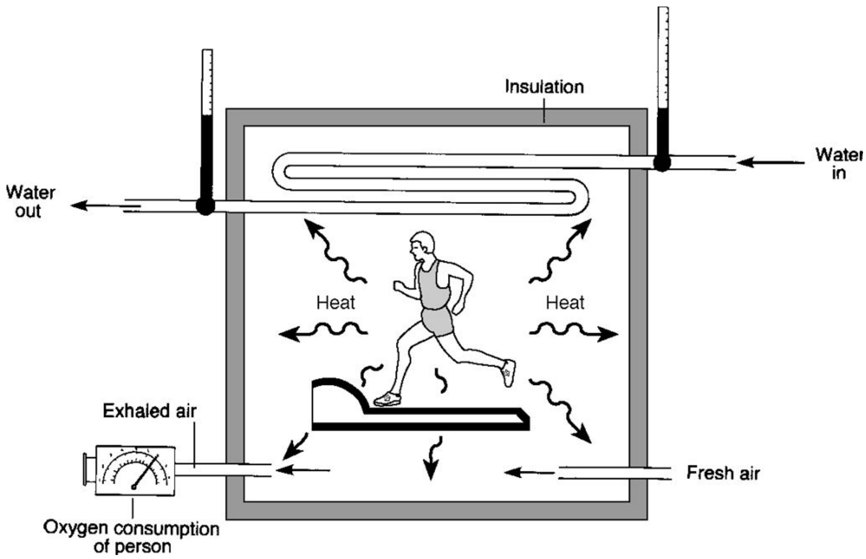

Figure. 2.1 Direct calorimetry

All calorimeters consist of the calorimeter proper and a jacket or a bath, which is used to control the temperature of the calorimeter and the rate of heat leak to the environment. For temperatures not too far removed from room temperature, the jacket or bath contains liquid at a controlled temperature. For measurements at extreme temperatures, the jacket usually consists of a metal block containing a heater to control the temperature. With nonisothermal calorimeters, where the jacket is kept at a constant temperature, there will be some heat leak to the jacket when the temperature of the calorimeter changes. It is necessary to correct the temperature change observed to the value it would have been if there were no leak. This is achieved by measuring the temperature of the calorimeter for a time period both before and after the process and applying Newton's law of cooling. This correction can be avoided by using the technique of adiabatic calorimetry, where the temperature of the jacket is kept equal to the temperature of the calorimeter as a change occurs. This technique requires more elaborate temperature control, and its primary use is for accurate heat capacity measurements at low temperatures.

In calorimetric experiments it is necessary to measure temperature differences accurately; in some cases the temperature itself must be accurately known. Modern calorimeters use resistance thermometers to measure both temperatures and temperature differences, while thermocouples or thermistors are used to measure smaller temperature differences.

3. Limitation of direct calorimetry

- The limitations of direct calorimetry are the expensive of the construction of suitable chamber.
- Experiment is done by chamber or calorimetry, the subjects are restricted their activity, since change their usual activity patterns.
- And the fact that such investigations must be made in the laboratory.

This is not applicable to measure in free-living conditions.
- Direct calorimetry is the only method by which continuous recording of energy expenditure for a long time can be obtained. It should consider the investigator time.

B. Indirect Calorimetry

1. Definition

The measurement of the amount of heat generated in an oxidation reaction by determining the intake or consumption of oxygen or by measuring the amount of carbon dioxide or nitrogen released and translating these quantities into a heat equivalent.

The term 'indirect' refers to the fact that energy production is determined by measuring O_2 consumption and CO_2 production rather than directly measuring heat transfer (direct calorimetry). It is less expensive than direct calorimetry. Its disadvantages are primarily that it remains an expansive technique and requires the use of a hood or a mask that the subject may find confining.

2. Method

There are tow main indirect calorimetry systems for the measurement of VO_2 and hence EE.

Firstly, the 'closed-circuit' method requiring subjects to be isolated from the outside air works well for measuring resting or basal metabolic rate (Figure. 2.2a) [4]. The subject breathes air from the atmosphere. The composition of the air flowing in and out of the lungs is measured to estimate oxygen consumption [3].

Secondly the 'open-circuit' method is more suited to measure exercise metabolism. In this method, airflow and percentage of oxygen and CO_2 are measured precisely to calculate VO_2 and CO_2 consumption (VO_2) and hence respiratory exchange ratio. This method is particularly useful for long-term measurements with subjects at rest or performing only light exercise (Figure 2.2b). The subject inhales via a face mask from a container filled with oxygen. Expired air goes back to the container via soda lime, which absorbs carbon dioxide. Changes in the volume of oxygen in the container are recorded as the volume of oxygen consumed.

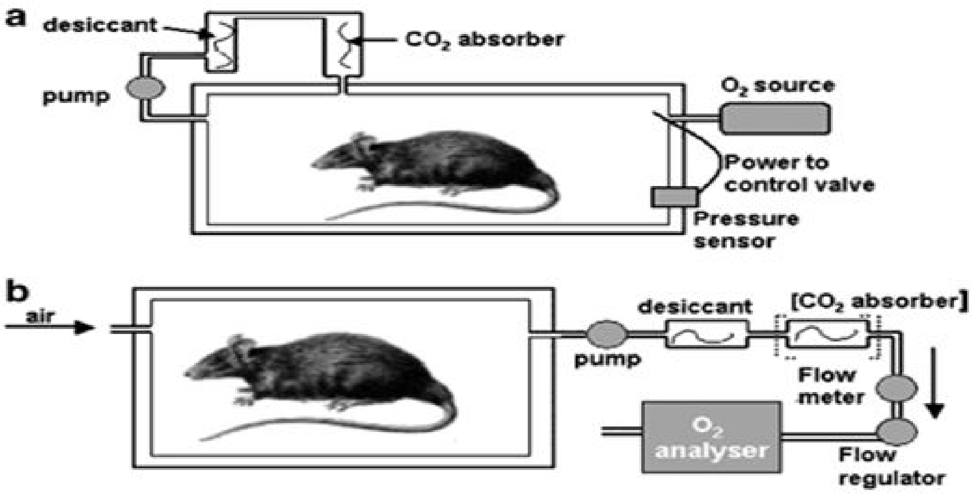

Figure 2.2 Indirect calorimetry.

a. Closed-circuit indirect calorimetry

b. Opened-circuit indirect calorimetry

3. Limitation of indirect calorimetry

- Indirect calorimetry can be used in the field but continuous recording of activity is difficult. Because this method requires subjects to wear apparatus on face or in mouth, such as ventilated hood system [25].
- This method also needs expensive and sophisticated equipment. For example, oxygen consumption measurements often suffered due to the response time of oxygen analyzer [29], this issue related to the sensitivity of oxygen analyzer.
- This method can only be accurately used for measuring resting or basal metabolic rate and light exercise during steady state exercise. Steady state conditions are necessary to accurately predict cellular metabolism through measurements of gas exchange in the airways. If a patients has rapid change in minutes ventilation during a study (hyper or hypoventilation), the measured carbon dioxide at the airway will not accurately reflect cellular levels of carbon dioxide. Thus VO_2 will be artificially higher when the patient hyperventilates and lower during periods of hypoventilation [28]. This is a common problem during mechanical ventilation, especially when a mode that allows of spontaneous ventilation is used.
- And this method need consider the consider the system leak problem, especially during mechanical ventilation, area common problem. Failure to capture all of the exhaled volume into the metabolic computer will result in measurement errors. Care should be taken to ensure a tight seal around all circuit fittings as on the artificial airway cuff.

C. Heart Rate Monitoring

1. Definition

Generally, there was a fairly close and linear relationship between HR and EE or VO_2 during steady exercise [6]. This technique has also been validated against electrocardiography(ECG) monitoring. To date, HR is noninvasive, low cost and easy to measure. EE is easily accessible from HR data. HR-based EE-estimates are relatively accurate in steady exercise conditions[7].

However, there are still some limitations. HR does not increase as steeply for a given change in EE, probably due to changes in stroke volume between lying, sitting and standing [8]. For example, HR can vary due to emotional stress, which would result in disproportional rise in HR for a constant VO_2. At a low level of activities estimations of EE from HR may have errors of up to 30% in individuals, although the average for a group of individuals is likely to be within 10% of the true value.

2. Method

Spurr et al., (1988) developed one method that involves the determination of FlexHR [5]. With this method, an individual's resting metabolic rate (RMR) and HR-VO_2 curve across exercise of varying intensities are first determined. The FlexHR is then calculates as the mean of the highest HR achieved at rest and the lowest HR achieved during exercise. If a given HR observed during field activity is below the FlexHR, then energy expenditure is determined based on RMR. If a given HR is above FlexHR, then energy expenditure is determined based on the individual's HR-VO_2 curve [9]. Even though this method takes into account individual variability in the slope of the HR-VO_2 relationship, it is time-consuming to establish individualized calibration curves.

3. Limitation of heart rate monitor

- Heart rate has in estimates of energy expenditure. It can occur during sedentary and light activities because HR can be elevated due to their factors such as stress, hydration, and environmental factors [23].
- In particular, HR are affected by biology [10]. Because subject characteristics such as age, sex, body posture, and fitness level affect the slope and intercept of a linear HR-EE relationship.
- This method requires individual laboratory calibration curves for accurate estimates of EE [24].

D. Motion Sensors

1. Definition

Motion sensors are mechanical and electronic device that pick up motion or acceleration of limb or trunk, depending on where the monitor is attached to the body. There are several types of motion sensors that range in complexity and cost from the pedometer to triaxial accelerometer [12]. Among motion sensors, triaxial accelerometers which measure acceleration in the vertical, horizontal and mediolateral plane are the most commonly used. But it is unable to detect certain movements such as cycling and upper body exercise. Some devices failed to detect the increased energetic cost of walking on a steep incline.

Lately, a relatively new, commercially available device for assessing energy expenditure, called SenseWear pro armband (SWA) [11]. It monitors various physiological and movement parameters. These data together with demographic information including gender, age, height, and weight, used to estimate energy expenditure with a generalized algorithm. However, its ability to detect energy expenditure during exercise remains questionable. The SWA can not accurately access EE.

2. Method

A new device for assessing energy expenditure, called the SenseWare armband (SWA), came on the market. The device is worn on the right upper arm over the triceps muscle, It has an ergonomic design and can be easily slipped on and off, and it does not interfere with day-to-day acidities or sleeping [13]. The device has multiples sensors that can measure various physiological and movement parameters simultaneously, including body surface temperature, skin vasodilatation and rate of heat dispassion, as well as a two-axis accelerometer. Data on these parameters, together with demographic information including gender, age, height, and weight, are used to estimate energy expenditure with generalized algorithm, the principal difference between this system and the devices discussed previously is the inclusion of a heat flux sensor [14]. This allows the system to detect a change in heat produced as a result of metabolism.

3. Limitation of movement sensors

- Accelerometers are generally worn on the hip which limits their ability to detect certain movements such as in weight lifting, cycling, and upper body

exercise [15].
- There are also unable to discriminate walking or running performed on soft or graded terrain.

E. Combined Heart Rate and Motion Sensors

1. Definition

HR monitoring and accelerometers combined methods are most often chosen for assessing physical activity and energy expenditure. However, there are limitations associated with each method when used alone. The HR monitoring is primarily due to biological variance. HR found to be affected by age, gender and psychological stress [16]. That means it is not possible to differentiate between increases in heart rate due to activity or those due to stress. On the other hand, the limitations of movement sensors, when used alone, they cannot quantitatively estimate all physical activities, as mentioned before, such as cycling and rowing. The technique is generally unable to adequately detect increases in energy expenditure. These limitations reduce the usefulness of movement sensors alone as instruments to estimate EE in field studies. As errors associated with the two methods are not inherently related [17].

The researchers have studied the combined heart rate and movement sensors for measuring energy expenditure. In these studies, HR and movement counts were recorded at the same time. The activity data were used to separate the HR data into activity and inactivity, which improved the estimates of EE.

AirBeat system that provide HR and mobility index has developed. Until now, a prediction equation using them has not been made for it. Therefore, a well designed experiment is needed to provide more precise prediction of energy expenditure than similar instruments by combining HR and mobility index.

2. Method

Indirect calorimetry is considered to be a precise technique for the measurement of metabolic rate. The principle of indirect calorimetry can be explained by the following relationship:

Foodstuff + O_2 ---------------> Heat + CO_2 + H_2O (5)
(Indirect Calorimetry) (Direct Calorimetry)

Since a direct relationship exists between O_2 consumed and the amount of heat produced in the body, measuring O_2 consumption provides an estimate of metabolism. In order to convert the amount of O_2 consumed into heat equivalents, it is necessary to know the type of nutrient (i.e.,carbohydrate, fat, or protein) that was metabolized. The energy liberated when fat is the only food stuff metabolized 4.7 kcal (or 19.7 kJ)/L O_2, while the energy released when only carbohydrates are used is 5.05 kcal (or 21.13kJ)/L O_2. Although it is not exact, the caloric expenditure of exercise is open estimated to be approximately 5 kcal (or 21kJ) per liter of O_2 consumed.

The open-circuit spirometry is used to measure oxygen consumption. The volume of air inspired is measured with a device that is capable of measuring gas volumes. The expired gas from the subject is channeled to a small mixing chamber to be analyzed for O_2 and CO_2 content by electronic gas CO_2 in the expired gas is sent to a digital computer by way of a device called an analog-to-digital converter (converts a voltage signal to a digital signal). The computer is programmed to perform the necessary calculations of volume of O_2 consumed per min and the volume of carbon dioxide produced.

In short, the energy expenditure during exercise is estimated by measuring VO_2 (liter per min) using open-circuit spirometry, and then converting it to kcal in following way:

$$EE(kcal/min) = VO_2 \times \text{Energy cost of Oxygen (about 5 kcal/liter)} \quad (6)$$

3. Limitation of combined heart rate and movement sensors

- This method requires HR-VO_2 equations to be developed on each individual for both leg and arm work [18].
- This method should consider if multiple sensors are used. The subjects wear cumbersome fitting, which can affect the accuracy of energy expenditure estimation [26].
- In addition, the data analysis is time consuming, thus limiting its use to studies involving small samples [27].

The following table 2.1 gives a summary of these methods.

Table 2.1: Comparison of different methods outcome.

Method	Measurement	Outcome
Room Calorimetry	CO_2 and VO_2	EE
Indirect Calorimetry	CO_2 and VO_2	EE
Movement Sensors	Acceleration (i.e. body movement)	Counts
HR Monitoring	HR	EE

III. Experiment

In this study, we chose combined heart rate and movement method to estimate human body energy expenditure. The heart rate and movement index can be monitored in realtime and wireless around 400 meters.

A. Subjects

Thirty male students from Chosun University (Table 3.1) were participated in gradual exercise test on the treadmill for estimating caloric expenditure in accordance with the Bruce protocol (Table 3.2) [19]. The whole process from walking to running total 12 minutes (Figure 3.1).

Table 3.1 Subjects description

	Total (n=30)	SD
Age, yr	26	0.82
Weight, kg	65.25	4.57
Height, m	1.69	0.04
BMI, kg/m2	22.6	0.69

Values are means; SD, standard deviation; BMI, body mass index.

Table 3.2 Participants' activity on treadmill base on Bruce Protocol

Slope (grade)	Speed (km/h)	Time (min)	Stage
10	2.7	3	1
12	4.02	6	2
14	5.47	9	3
16	6.76	12	4

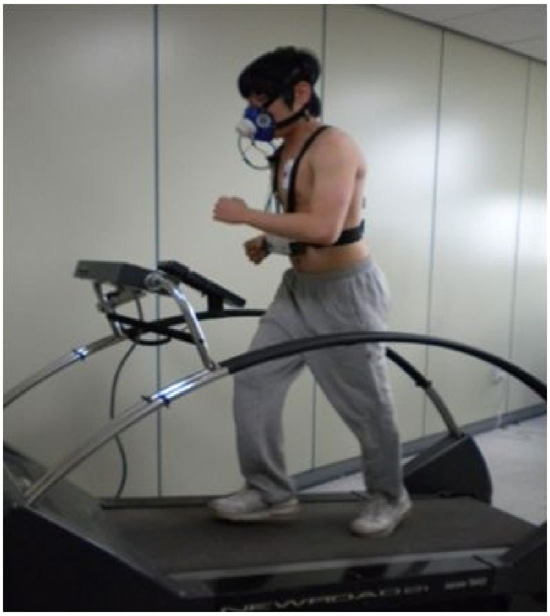

Figure 3.1 The participant underwent experiment on treadmill.

B. Equipment

1. AirBeat System

A patch-type sensor module (AirBeat System) for real-time monitoring of heart rate and agility index has been developed and evaluated as it can be seen in Figure 3.2, Table 3.3.

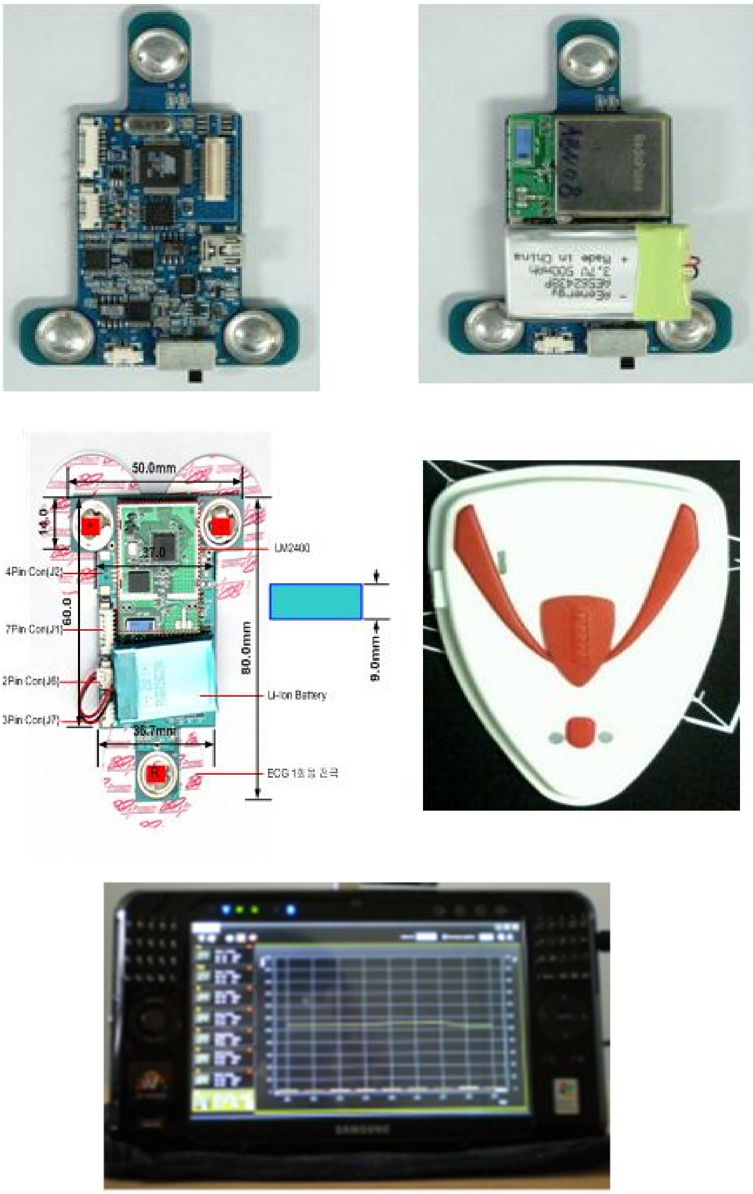

Figure 3.2 AirBeat System overview.

Table 3.3 The specification of AirBeat system.

Items	Performance
Channel	8ch
Resolution	12bit
Sampling Rate	200/s
Frequency B.W.	1Hz~50Hz
Power	LI-ION
Max HR	250/m
HR Detection Error	Below 10%
Power	±3.3V, 3.3V
Comm. Module	ZigBee
Comm. Distance	400 m
MCU	MSP430 (TI,USA)
Electrode	Jumper setting available
Size	6 cm * 9 cm, 20g

The major components of the system are the sensor board, the rubber case, and the communication module. The small size sensor is patched on the athlete or patient's chest for obtaining physiological data. The physiological data include heart rate, movement index, humidity and temperature. The relation test for heart rate has shown the error rate within 2% compare with the CASE system (GE, USA) (Figure 3.3).

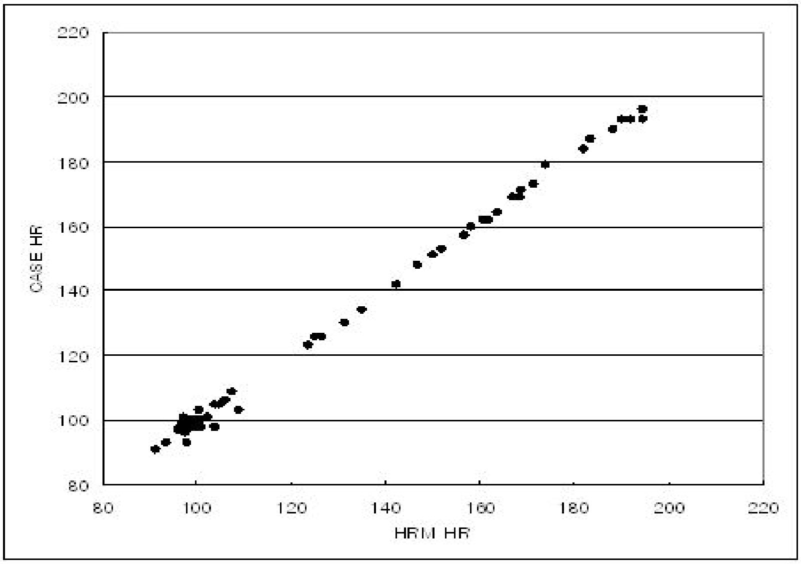

Figure 3.3 The results of comparison test of our heart rate monitor and CASE system.

We use a 3-axis accelerometer which is low power consumption and very small size. The correlation coefficient between the average agility index and conventional agility point has been found in the range of 0.8 to 0.9. The temperature accuracy is 0.4 (K) at 25℃, the humidity accuracy is ±3%. The commercial Zigbee telecommunication is used for communication, and the distance over 400 meters in the open space. According to the Bruce protocol test, the change of heart rate and agility index can be efficiently monitored and measured with the device.

2. Gas System

Gas system is used to measure energy expenditure. The predicted values were compared from indirect calorimeter Cosmed $K4b^2$ (Cosmed, Srl, Italy) (Figure 3.4). The gas system can realtime monitor VO_2, VCO_2 (Figure 3.5), and EE (Figure 3.6). The data can export to Excel form for analysis with AirBeat system. The gas system can be wore by one person for one time. It costs time to guide and help the participants wearing. For one participant, the whole experiment need around half an hour. And the experiment can not do in anytime of the day. Since it should consider the participants body condition, like no coffee, no smoking, and after meal 2 hours later. Hence, the efficiency is not high.

Figure 3.4 Gas system overview.

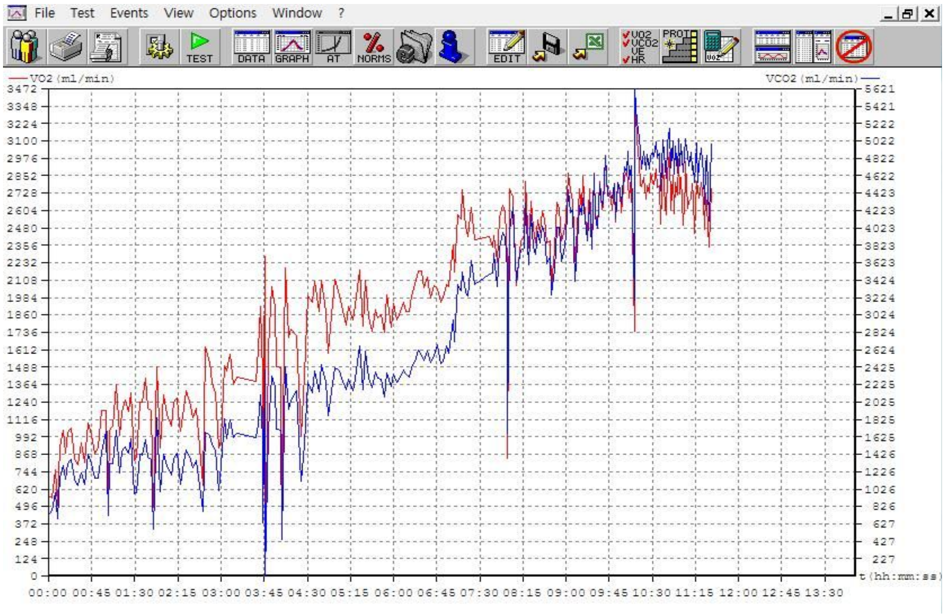

Figure 3.5 Gas system real-time monitor VO_2 and VCO_2

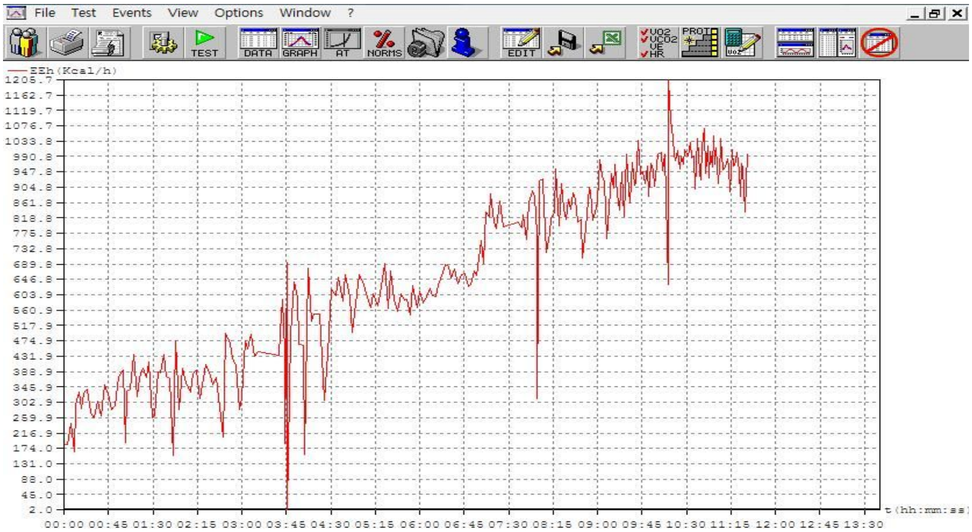

Figure 3.6 Gas system real-time monitor energy expenditure

C. Procedure

For determination of the VO_2 / HR regression line, the subjects reported to the laboratory at 3 PM, after lunch at least 2h later, having avoided substantial physical exercise and smoking that day. VO_2 and HR were recorded during the entire periods (Figure 3.7): 1: warm-up, 2: five3-min periods of walking or jogging on a treadmill at different speeds, 3: recovery. The heart rate was recorded with the Airbeat system and O2-intake was measured using open-circuit system.

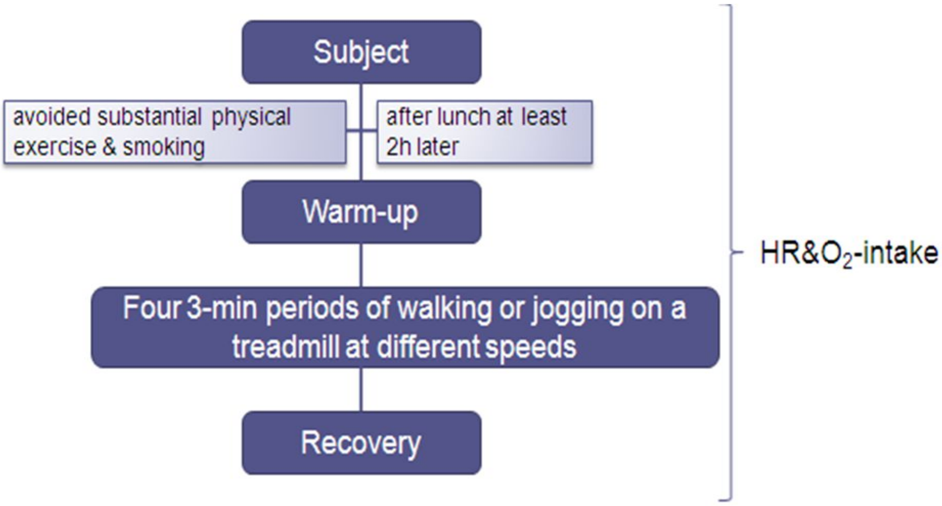

Figure 3.7 Experiment procedure.

D. Data analysis

All data were saved in Excel 2003 format. The time were expressed in seconds and beats per min (bpm) for heart rate. Oxygen consumption and carbon dioxide production were expressed in ml per minute (ml/min). Energy expenditure were expressed in Kcal per minute (Kcal/min). All of the data were a rang in same excel sheet then average each group data. The data can be classified the following groups: Time-HR, Time-VO_2, Time-VCO_2, and Time-EE. These data then were converted to HR-EE, was estimated energy expenditure, then compare with measured the EE (Time-EE). Figure 3.8 shows the algorithm of estimating energy expenditure [21]. This algorithm can be modified depend on the experiment results.

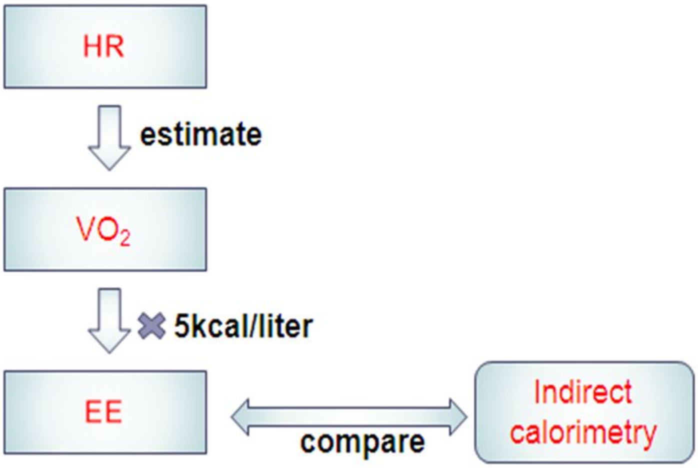

Figure 3.8 Algorithm for estimating energy expenditure.

IV. Result and Discussion

During the test, the participants were patched AirBeat sensor for measuring HR, MI, temperature and humidity in real time. HR and MI are showed in Figure 4.1.

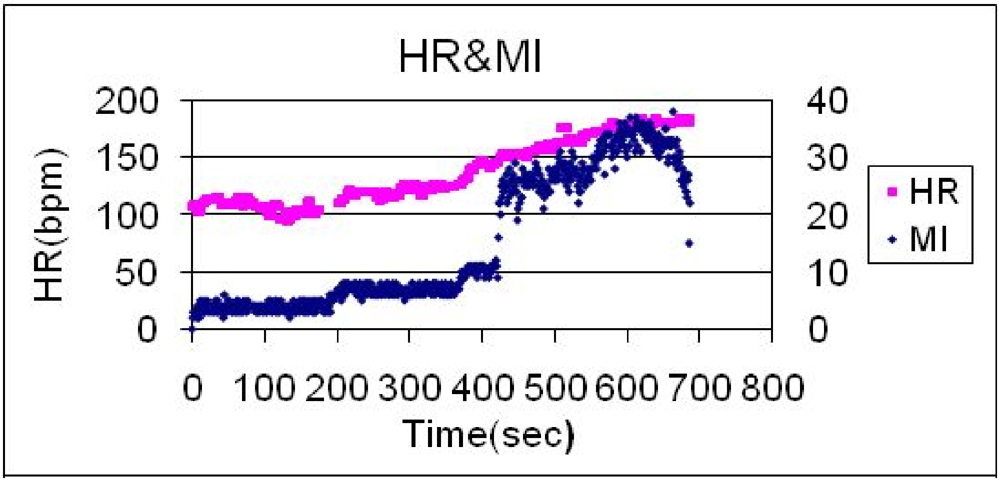

Figure 4.1 Heart rate and movement index are monitoring in real-time.

From Figure 4.1, we can see the MI linear was divided four stages, since the Bruce Protocol has 4 stages. The last 3 minutes is running, clearly the linear is became higher than walking. HR generally keep linear.

The indirect calorimetry system measured the oxygen consumption as Figure 4.2. The participants increased the oxygen consumption as the activity intensity improved. The last three minutes the oxygen consumption is more than the beginning. For convert HR-VO_2 figure, we unified the time in same unit (Figure 4.3). During the test, some false values were deleted, the others are original data.

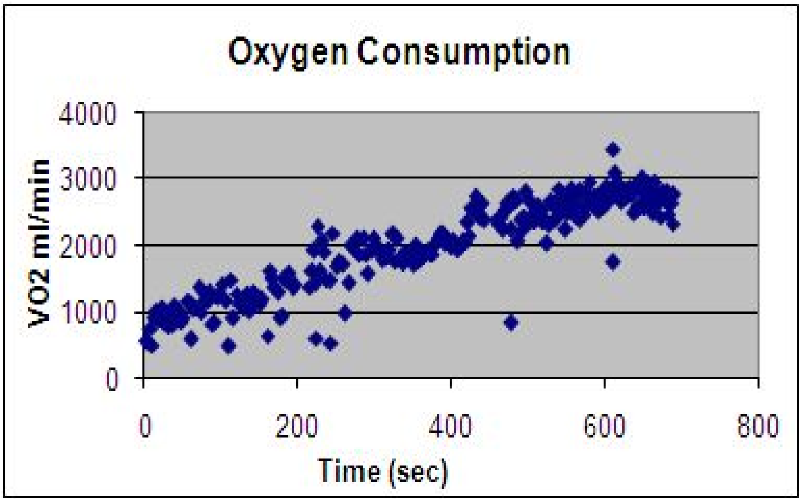

Figure 4.2 Realtime monitor oxygen consumption.

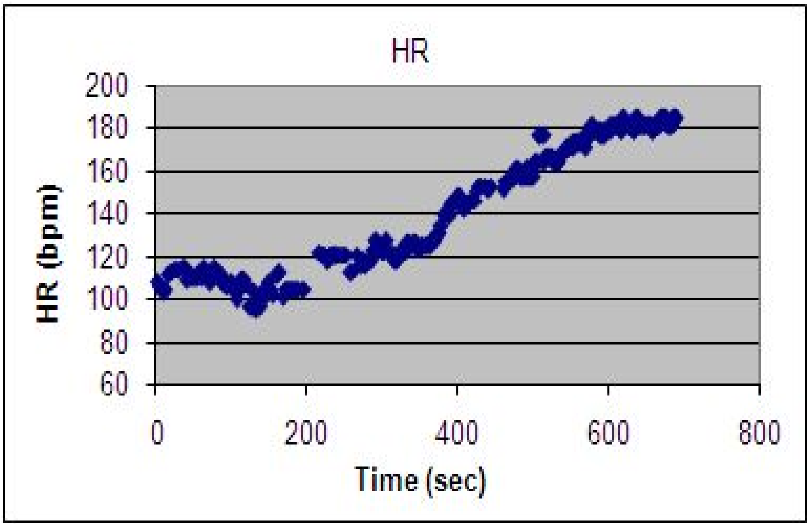

Figure 4.3 AirBeat system realtime monitor heart rate

Figure 4.4 shows the HR and VO_2 linear relationship (R^2=0.78). R-Squared is a statistical term saying how good one term is at predicting another [22]. If R-Squared is 1.0 then given the value of one term, you can perfectly predict the value of another term. If R-Squared is 0.0, then knowing one term doesn't not help you know the other term at all. More generally, a higher value of R-Squared means that you can better predict one term from another. R-Squared is most often used in linear regression. Given a set of data points, linear regression gives a formula for the line most closely matching those points.

It also gives an R-Squared value to say how well the resulting line matches the original data points. From the figure, the dots are not straight line but trend to linear line. The algorithm needs to improve. If we got the straight line, from the HR-VO_2 figure we have the heart rate value then we can estimate the VO_2 in realtime. The VO_2 value can help us to estimate the energy expenditure. The figure can be also polynomial expression. For hight accurate estimation, it need amount of experiments. It also depends on the participants' age, gender, body condition, etc factors. In this thesis all of the participants are young male students.

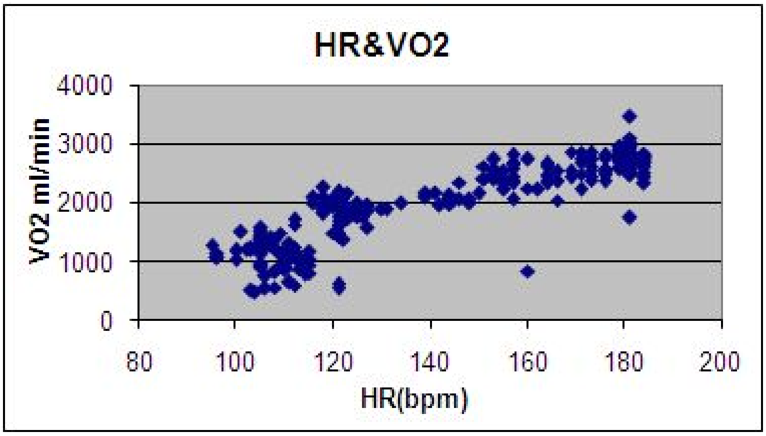

Figure 4.4 HR and VO_2 linear relationship.

The caloric expenditure of exercise is open estimated to be approximately 5kcal (or 21kJ) per liter of O_2 consumed. Figure 4.5 shows the comparison between the estimated and measured energy expenditure. The blue line is measured energy expenditure, and the red line is the estimated energy expenditure. From the Figure 4.5, the wireless HR-MI sensor overestimated energy expenditure during low activities and underestimated the energy cost of intensity activities ($p<0.001$) [20].

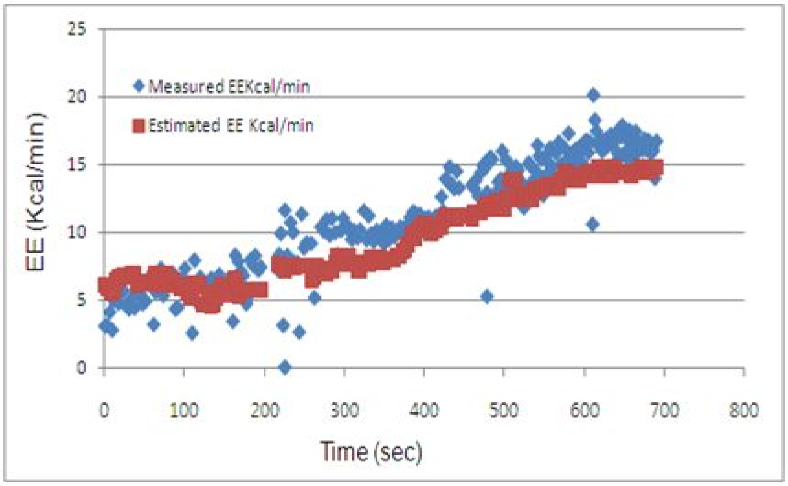

Figure 4.5 Comparison between estimated EE and measured EE.

V. Conclusion

Energy expenditure are used in a variety of applications. The rate of chronic disease such as obesity, hypertension, and diabetic is rapidly increased. Excess nutrient and energy expenditure imbalance are considered major important cause of chronic disease. Energy expenditure is ofte assessed along with energy intake for weight management purpose. The assessment of energy expenditure can play a role in promoting a healthy lifestyle.

Energy expenditure measurements are also important in the study of relationship between physical activity and health. In addition to health promotion and health-related research, energy expenditure measurement can be utilized in fitness and athletic training. Athletes and active sports participants, together with their coaches and personal trainers, can plan their nutrition by utilizing information on expended calories. During fitness training it is often typical to compare energy expenditure values between different exercises, and to select the activities that are perceived most positive and also have relatively high energy expenditure. Coach and athlete can design athlete's daily diet by considering the total energy expended in daily training and living. This is an important issue because a proper nutritional state supports optimal recovery. And body weight and composition can be optimized by utilizing the information on daily energy expenditure.

The method of combine heart rate and motion sensors is most often chosen for assessing physical activity and energy expenditure. I choose this topic because it has many advantages. It overcomes the major weakness associated with HR monitoring or motion sensing alone. For example, HR monitoring is not subject to error in movement sensing such as in detecting the level of activity during resistance exercise, swimming, and cycling. Likewise, movement sensing complements HR monitoring as it allows differentiation between increased HR caused by physical activity and that caused by non-exercise related influences.

In previous study, the AirBeat system has good performance. The relation test for heart rate has shown the error rate within 2% compare with the CASE system (GE, USA). The correlation coefficient between the average agility index and conventional agility point has been found in range of 0.8 to 0.9. The temperature accuracy is 0.4 (K) at 25℃, the humidity accuracy is ±3%. These performance provide the condition for measuring energy expenditure.

The chest patched type wireless sensor module AirBeat system has strong relationship with VO_2 (R^2=0.78). However the wireless HR-MI sensor overestimated energy expenditure during low activities and underestimated the energy cost of intensity activities ($p<0.001$).

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List of Publications

Li Meina, Kyeong Ho Byun, Hyo Jung Kim, Jaemin Kang, and Youn Tae Kim, "Patch Type Sensor Module for Estimating the Energy Expenditure", International Conference on IEEE Sensors, New Zealand, Nov. 2009.

Li Meina, Dinh Luan, Ji Hwan Lee, and Youn Tae Kim, "In-situ Monitoring of Energy Expenditure by the Application of Wireless Patch Type Sensor Module", AMA-IEEE Medical Technology International Conference on Individualized Healthcare, Washington. DC, USA, Mar. 2010.

Dinh Luan, **Li Meina**, Ji Hwan Lee, and Youn Tae Kim, "Algorithm for Real-Time Wireless Monitoring of Heart Rate and Agility Index", AMA-IEEE Medical Technology International Conference on Individualized Healthcare", Washington. DC, USA, Mar. 2010.

Li Meina, Jang Myoung Kim, and Youn Tae Kim, "A Combined Heart Rate and Agility Index Sensor for Estimating the Energy Expenditure", submitted on International Conference of IEEE Sensors, Hawaii, USA, May. 2010.

Li Meina, Youn Tae Kim, "Development of Patch-Type Sensor Module for Real-Time Monitoring of Heart Rate and Agility Index Design", submitted on International Journal of Sensor and Actuator A, May. 2010.

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본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(○) 반대( )

2010년 8월

저작자: 리미나 (서명 또는 인)

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