Mobile Energy Expenditure Tracking System Based on Heart Rate and Motion Providing Extra Extensions for Personalized Care

Hong-Hui Chen, Yu-Hsin Chen, Tung-Chien Chen and Liang-Gee Chen

Abstract— **In order to keep a healthy body it is very important to have balanced energy expenditure (EE). The proposed system utilized the phonocardiogram (PCG) and motion from the user to generate the heart rate. The heart rate has been deemed as a very reliable index to estimate the EE of human body. Efforts are put on developing our system to deal the situations when severe interference coupled into the system while the user is exercising. Accelerometer is used to get the motion status and also the posture of the user which is monitored to determine any anomaly. If anomaly is detected, the system actively issues notification to whom that might give back a timely aid.**

I. INTRODUCTION

People are doing exercise to control their weight and keep their cardiovascular system healthy. Heart disease has been top ranking cause of death in USA for several years [1]. In Taiwan, it is also a high-ranking disease that takes away people's life. Keeping a regular exercise help people to lower the risk of cardiovascular disorder. To achieve an effective exercise, many guidelines exist helping people to check if they post a proper activity strength on their bodies. In the mean time it is also important to have a good diet to keep fit. The goal is to have balanced energy expenditure (EE). A famous rule of thumb for checking one's body condition is the body mass index (BMI). It is a index to reflect if the shape of one's body is in good condition.

Knowing how much EE of one's body make it easier to achieve a good BMI requirement. Previous works [2][3][4][5] have been done to estimate the EE. In these researches, the EE has shown a very strong linear relationship with the heart rate. However, previous researches also point out that the heart rate is easily affected by the human emotion or is raised in emergency situation. Therefore, previous works proposed some kinds of motion indexes incorporated in the estimation algorithms to overcome this problem. However, there are still problems unsolved. First many of them require multiple electrodes contacting with the skin when doing heart rate measurement. If one electrode is not in a well-configured condition, the measured signal is invalid. Secondly, the heart rate is measured based on Electrocardiograph-based technology. There is no ready to use Electrocardiograph (ECG) interface circuit in most of the available mobile devices, which are the main target devices used in our research, in the market. Extra cost is required to provide the additional device to capture and amplify the signal from human body.

In our proposed NuWa1 system, we utilize the microphone of the mobile device to get heart sound signal namely the phonocardiogram (PCG). Heart rate is extracted from PCG. Our algorithm can not only deal with the stationary or quasi-stationary subjects but also deal with the subjects under moderate to intense exercise. The term "quasi-stationary" means that the subjects move slightly and no obvious sound is made. The output of stable heart rate is achieved and no extra hardware is required. Therefore, based on the output of the heart rate EE could be tracked. Though vests with packets may be required to hold the mobile device in suitable position around the chest, it is still a more easy-to-use and less expensive solution for calculating heart rate compared to ECG-based technology.

To provide extra care for the user, NuWa1 utilizes more sensors and facilities in mobile devices. For example, the accelerometer is utilized in a two-fold fashion. First it determines the motion status which is utilized to adaptively adjust the EE calculation of the system. Secondly it is used to detect anomaly during the exercise trip. Notification is issued with as much information as possible when emergency situations are detected. These achieve an active guard mechanism to protect the users. Besides, if weight history is provided, our system could learn the characteristic of the user and achieve a more precise EE calculation. The reminder of this paper is organized as follows. First the system design is introduced to give an overview of the NuWa1 system. In section III the description of several use cases is given. Finally the conclusions and future works are given.

II. SYSTEM DESIGN

A. Core Application Flow

The core application flow of the NuWa1 system is depicted in Fig. 1. In the initial setting phase, the parameters of height, age and weight target are input to the system. The heart rate tracking phase is one of the most important functional blocks in our system. High-sensitivity microphone is utilized to record the sound from the users' chests. iPhone 4 and iPod touch 4 both provide good audio recording quality. Therefore we select iPod touch 4 as the device to develop heart rate extraction algorithm.

Hong-Hui Chen is PhD student in Department of Electrical Engineering in National Taiwan University sernc@video.ee.ntu.edu.tw

Yu-Hsin Chen is master student in Department of Electrical Engineering in National Taiwan University allenhsin@gmail.com

Tung-Chien Chen is post-PhD researcher in Department of Electrical Engineering in National Taiwan University djchen@video.ee.ntu.edu.tw

Liang-Gee Chen is professor in Department of Electrical Engineering in National Taiwan University awarded as IEEE fellow in 2001 lgchen@video.ee.ntu.edu.tw

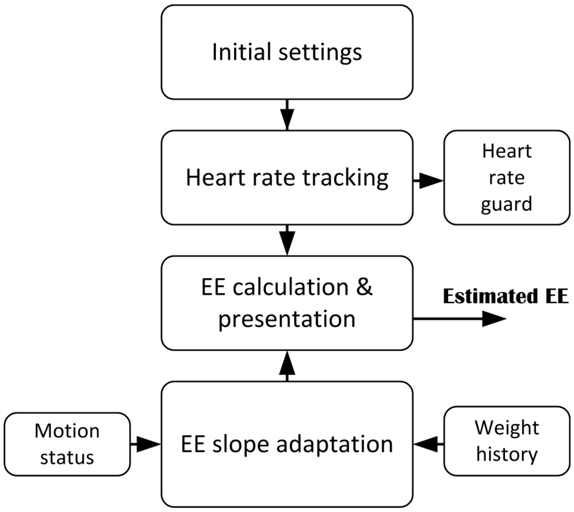

Fig. 1: Core application flow of NuWa1 system

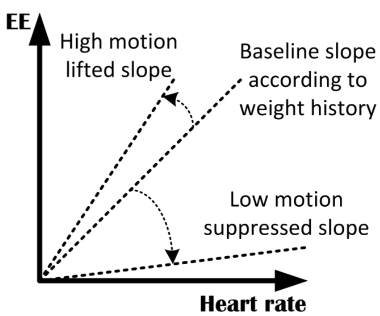

Fig. 2: Adaptation of EE calculation slope

The heart rate is linearly proportional to EE [3][4][5] and this makes it a good indirect measurement of EE. However, everyone has his/her particular slope for the EE versus heart rate. Therefore, though we set up a baseline value for this slope, it should be adapted to fit users' characteristics. The weight history helps to achieve the first adaptation in our system. As for another adaptation, researches [3][5] point out that heart rate is easily affected by users' mental emotions, and a good solution is to take body motion into consideration.

The introduction of micro electro mechanical systems (MEMS) technology makes it easy to manufacture a small and cost-effective accelerometer. We use the 3-axis accelerometer to collect the motion status from user. If no obvious motion is captured in a predefined period of time, the slope is lower accordingly thus only little EE is achieved. The two adaptation mechanisms are shown in Fig. 2. The baseline slope is adapted according to the weight history whereas it could be further adjusted by motion status. Our system gives extra bonus EE if the user do induce high motion activities to the accelerometer.

NuWa1 is capable of learning personalized information and this learning ability make it calculate the EE of the user more precisely. The EE is converted to more understandable index, like calorie, metabolic equivalent of task (MET) in the

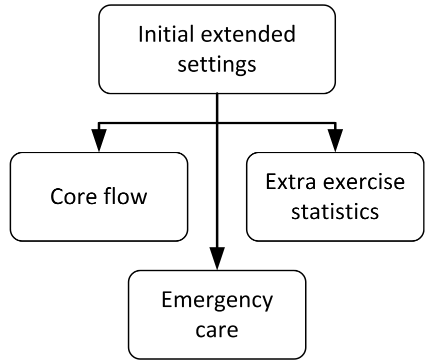

Fig. 3: Extended application flow of NuWa1 system

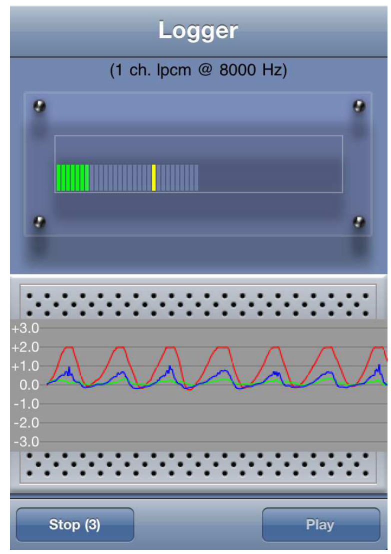

Fig. 4: Logger application. Reuse 2 sample projects from Apple Inc. to complete this software.

EE calculation and presentation stage. BMI is also calculated if height information is available. Furthermore if user has input the weight target, NuWa1 will issue suggestions after using the system a certain amount of time so that user can know how to adjust their exercise strength. Furthermore in the NuWa1's core application flow, a protective personal care, heart rate guard, is introduced. According to [6], the maximal limit of the heart rate could be calculated by:

$$HR_{max} = 220 - age \tag{1}$$

If the extracted heart rate approaches this limit, the system warns the user by both acoustic and visual feedbacks.

B. Extended Application Flow

Our system is capable of conducting an extended application flow, as depicted in Fig. 3, by using more facilities provided by the mobile devices. In the extended flow, location-based functionality is achieved by introducing GPS/Wi-Fi/AGPS or other positioning technologies to track the position of the user. With the extra information, we

Fig. 5: Appearance of the vest with front packet

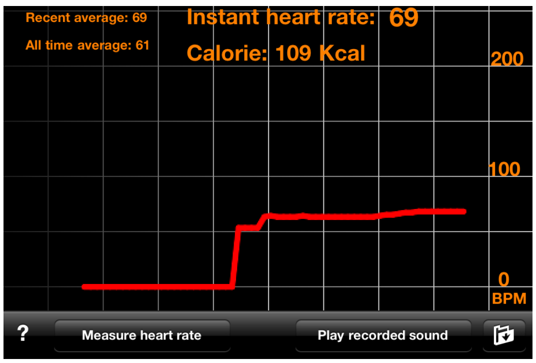

Fig. 6: GUI of the NuWa1 system running on iPod touch 4

could calculate how fast the user moves and log the moving trajectory of the user. For realizing more active care of the user, NuWa1 requires the user to input the plan of the exercise trip in order to monitor abnormal situations during this exercise. Notifications could be issued out from the device if any emergency status is identified. The 3-axis accelerometer does help in judging some of the situations. For example, if the user is conducting a jogging trip, and suddenly the user's posture becomes a lying one and the motion activity is almost zero for a certain period of time. It is better to notify someone about the abnormal situation. The 3-axis could precisely capture both the posture and motion status of the user at the same time. Practical notification mechanisms are explained more in section III.

We have developed a signal-logging software running on iPod touch 4 and its screenshot is shown in Fig. 4. This software is the combination of two example codes from Apple's iOS development center [7]. Besides we also design a vest with a pocket in front of the chest. It enables the users to place the iPod touch inside the packet with the recording hole for the microphone facing directly to the chest. The appearance of the vest is shown in Fig. 5. Current GUI of the NuWa1 is shown in Fig. 6.

III. USE CASES

There are several use cases in our system. Based on the involved algorithms and functionalities, they are described in the order from the simple one to the complex one.

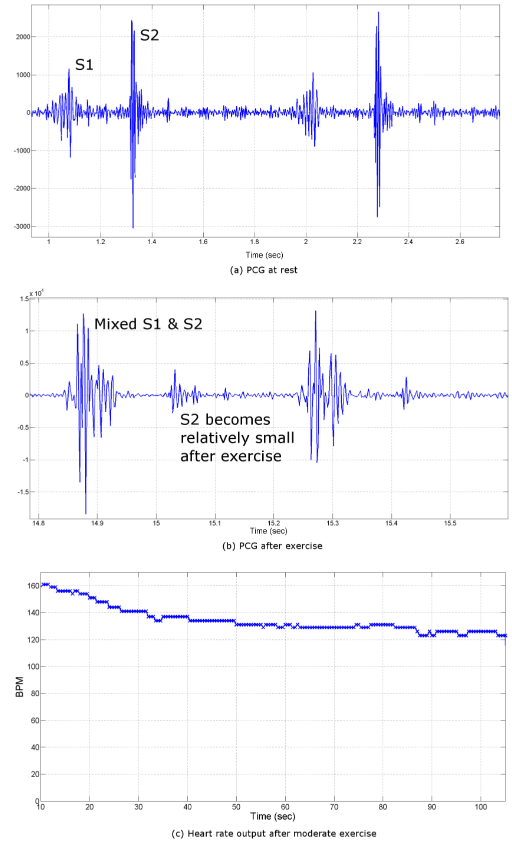

Fig. 7: (a) The heart sound when resting (b) The heart sound after exercise (c) Heart rate history after exercise

A. Stationary or Quasi-stationary

Measuring heart sound in stationary situation is a relatively easy task if the sensitivity of the sound recording equipment is high enough. The heart sound waveform of human in stationary or quasi-stationary situation when resting is shown in Fig. 7(a) recorded from iPod touch 4. The heart sound could be divided to two intervals namely systole and diastole and at most 4 kinds of sound namely S1$\sim$S4 spread in the two intervals. In the case of Fig.7(a) S1 and S2 are the more prominent two. Our algorithm [8] extracts the heart rate from the recording heart sound. We implement the algorithm on iPod touch 4 and test it on human subjects. The computation is in real-time and is able to produce stable heart rate which is then converted to corresponding EE output. The correctness has been investigated by manually segmenting heart beat from the recording waveform. Only negligible error exists.

B. Moderate to Intense Exercise

Our algorithm is extended to calculate the heart rate while the user is doing moderate to intense exercise. The waveform of the heart sound changes a lot when the heart rate goes fast. Fig. 7(b) shows the change of heart sound for the same person whose resting heart sound waveform is Fig. 7(a)

Because the sensitivity of the microphone is so high that even during a moderate exercise the coupled interference, such as, rubbing against the clothes and environmental

TABLE I: List of notification mechanisms

E-mail	Send e-mail to designated e-mail addresses
Cloud service	For example: Facebook/Twitter post
Short Message Service (SMS)	Send information by SMS to pre-set phone numbers when emergency occurs
Phone call	For example: call family member, friend and/or 911

acoustic noise, sometimes overwhelms the heart sound completely. To solve this problem our system not only conducts judgments according to extracted individual heart sound characteristics but also utilize the physiological properties to restore the losing heart rate segments where the interference is too high. The motion status also helps to determine a reasonable heart rate trend especially when the user still keeps a steady amount of activity. It is quite similar when the car goes into a tunnel and some navigation software could still predict the trace of the car. Current output of our system is depicted in Fig. 7(c). We are still working on developing a robust method to producing the heart rate when interference is very high.

C. *Exercise with Extra Guard against Emergency Situations*

To further take good care of the users, our system provides additional functionalities to actively monitor the status of the users. Currently these functionalities are:

1) Warning for approaching Heart rate limit
2) Detection of abnormal statuses in exercise trip

The first one warns the users if they are pushing themselves too hard which may make their heart rate approach the safe upper limit according to their ages. The second one deals with emergencies where the users lose their ability to operate the device directly, for example, some users might become faint in the middle of an exercise trip. Automatic notification is triggered by anomaly situations enabled by facilities, currently including 3-axis accelerometer, timer, positioning means, on the mobile device. Possible notification mechanisms are listed in Table I. Information sent out includes latitude and longitude of the users' location, nearby road or intersection name and even some famous landscapes around.

D. *Feedback Check*

Feedback check with the weight history helps to adjust the baseline slope of the heart rate vs. EE curve. Practically everyone has his/her own characteristics for EE while doing exercise. In the beginning, NuWa1 calculates the EE based on a baseline heart rate versus EE slope. If a certain user lose their weight too much with only a small EE, the slope of the curse will be lowered and vice versa. In this way, the correct slope of how much EE trades of the variation of the user's weight could be achieved adaptively. Currently we let users manually input their weight after they finish weight measurement. In the mean while, a more convenient way for inputting this measurement is viable. A weight scale equipped with Bluetooth is a possible choice for inputting the information to the mobile devices automatically. In addition, with the input information, a decent view of weight history could be presented to the users to let them monitor their body conveniently.

IV. CONCLUSIONS AND FUTURE WORKS

We propose NuWa1 system that adaptively tracks EE based on users' characteristics in order to assist them to manage their daily exercise. Owing to the progress of the mobile device, it makes more convenient and effective services available. For example, the introduction of high sensitive sensor like MEMS microphone and MEMS accelerometer make our system be capable of providing more functionalities to users. In our study, we use the data from microphone and accelerometer and convert them to meaningful representations in our system. The central heart rate calculation algorithm aims to deal with the severely coupled interference. In addition extra guarding functionalities are integrated to provide an active care during the exercise period. The posture and strange motion status of the users in abnormal situations are monitored. Once the abnormality is detected, multiple automatic notification mechanisms are invoked to inform someone as soon as possible for seeking their timely help.

Future works include enhancing the algorithm under severe interference and testing all the planed use cases. Moreover, improving the sense of comfort while wearing the vest is also important. A GUI with consistent user experience is also a key to its adoption. Great efforts should be put on making the system an extremely easy-to-use one.

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