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Exercises Intensity Estimation based on the Physical Activities Healthcare System

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Abstract

The suitable and personalize physical activities plan is a consequential and rewarding strategy to improve individual's health and keep his/her fitness. In this paper, a physical activities healthcare system (PATHS) based on the wearable wireless sensor unit is proposed to help persons evaluate the exercise intensity and estimate the caloric expenditure with electrocardiogram and motion sensors. The proposed system is useful for quantitative estimation of physical activities and helpful in monitoring progress of an individual's exercise program. Experiments based on the prototype system show that our system can estimate the exercises intensity and the caloric expenditure easily and conveniently.

1. Introduction

Regular physical activity, fitness and exercise are critically important for the health and well being of people of all ages. Research has demonstrated that virtually all individuals can benefit from regular physical activity, whether they participate in vigorous exercise or some type of moderate health-enhancing physical activity [1].

The feedback of physical activities can increase the exercisers' interest in workout. In order to maintain an efficient activity program and monitoring progress of an individual's exercise, we measure two important issues, the intensity of physical activity and caloric expenditure value during the whole physical activity progress.

The intensity of physical activity, or how hard exerciser's body is working, typically represents the amount of energy or effort a person expends in performing the activity. The moderate intensity of physical activity contributes significantly to healing the heart, as it can lead to fitness and energizing. Otherwise over-exercise can lead to fatigue and harm health. Due to much research on the exercise intensity, the heart rate increases predictably in response to physical activity. The relationship between exercise intensity and heart rate is an extremely linear. The greater is intensity, the higher heart rate [2]. According to its predictability, the heart rate can be used to describe the exercise intensities.

The caloric expenditure is a quantitative assessment of the activity energy expenditure which is noticed as one of the most important parameters guiding a healthy daily lifestyle. Physical activity may help individual control his weight by using excess calories that would otherwise be stored as fat [3]. Most foods and many beverages eaten and drunk contain calories, and everything done uses calories. Balancing the calories between eating and physical activity may help maintain weight and even health.

Recently, much research focus on how to measure the exercise intensity to help sports training and rehabilitating in order to understand and improve persons' physical performance using new technologies, such as Micro-Electro-Mechanical Systems (MEMS). We design a wearable device together with motion sensors and bio-sensors to monitor heart rate and estimate the activity calorie expenditure in real time. Furthermore, we combine sensor fusion and wireless technology into our system in order to get enough data to measure the exercise intensity accuracy and achieve better performance.

We have developed a physical activities healthcare system (PATHS) to monitor the ambulatory electrocardiogram and daily physical activities to estimate the intensity of physical activity and caloric expenditure value. The objective of PATHS is to investigate and develop a portable application to monitor the exercise progress in real time. The system collects sensor data and helps not only for athletes but also for rehabilitating patients or individual exercisers to develop individuated physical activity plans, and allows users to test their stress levels and detect overtraining.

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The rest of the paper is organized as follows. In the next section, we briefly outline the system architecture of PATHS. In Section 3, we describe heart rate and physical activities intensity. Caloric expenditure with physical activity is discussed in Section4. And then we present implementation and results in Section 5. Finally, we conclude in Section 6.

2. System Architecture

We have implemented the Physical Activities Healthcare System (PATHS) [4]. The system comprises four parts: the wearable wireless sensor unit (W2SU), local software and monitor, a hand-held device and remote expert system or service. The detail architecture is demonstrated in Figure 1.

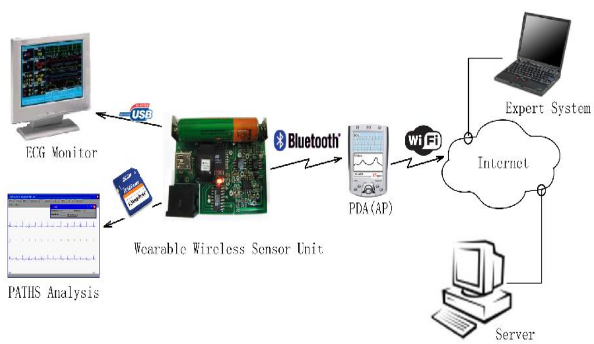


Figure 1: The system architecture of PATHS

In order to meet the requirements of wearable device, high speed data transmission, real-time monitoring functions and low power consumption, we propose the wireless measurement architecture to extend the functions of the conventional cardiac monitor. W2SU is the main part of PATHS, and it includes motion sensor, electrocardiogram signal processing circuits, microprocessor and several interfaces. Figure 2 shows the prototype of the W2SU.

To achieve the long distance monitoring and diagnosis, PDA works as an access point to connect W2SU with Internet, and then remote expert system or service center. As shown in Figure 1, PDA uses Bluetooth to transmit data with W2SU; Meanwhile, PDA uses Wi-Fi to connect to the Internet, and then access to the remote database. By this means, PATHS achieves data exchange between local and remote, as well as long-range medical diagnosis for local subjects.

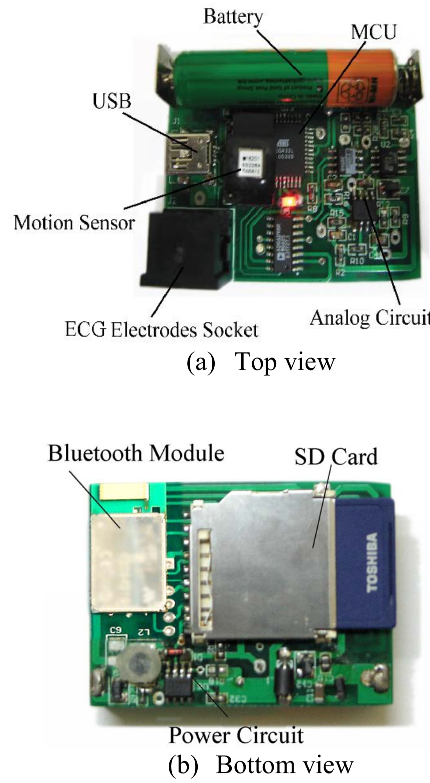


Figure 2: The prototype of the wearable wireless sensor unit

To sum up, our PATHS has several main features. First, large-capacity storage and high speed data transmission technology are used to effectively record of long term ECG and motion data. These data help subjects to develop individuated suitable physical activity plans and also to monitor the heart status continually. Second, the system has the function of cardiac event detector and can help subjects to monitor the exercise intensity immediately. Third, the use of Bluetooth technology facilitates communication and data exchange with the PDA. PDA can online display ECG waveform and calculate the caloric expenditure value at the same time. Finally, with the extensive use of the PDA as a wireless access point, PATHS connects to the network for the realization of telemedicine function.

3. Heart Rate and Physical Activities Intensity

The heart rate increases predictably in response to physical activity. The greater is intensity, the higher heart rate. Generally, Target Heart Rate (THR) is used to measure physical activities intensity. In our PATHS, two steps are used to get THR. Firstly, the heart rate is detected by the electrocardiogram. And then, THR is calculated as feedback of physical activities intensity.

3.1. Target Heart Rate

Target heart rate is a desired range of heart rate reached during the aerobic exercise which enables person's to receive the most benefit from the physical activity. This theoretical range varies based on one's physical condition, age and previous training. The target heat rate can describe persons' exercise intensity.

There are some methods to determine the intensity with heart rate. We use Karvonen method to estimate the target heart rate. The Karvonen method calculates a target range involves the person's resting heart rate and the maximum heart rate [2][5].

The Karvonen method factors in Resting Heart Rate (HR_{rest}) is used to calculate Target Heart Rate (*THR*):

$$THR = ((HR_{\max} - HR_{rest}) \times \% Intensity) + HR_{rest} \quad (1)$$

where, HR_{max} is the maximum heart rate according to the age of exercisers. The training intensity is from 60% to 90%. That means exercisers should be training between 60 and 90 percent of the maximum heart rate in order to burn fat and improve their fitness.

With PATHS, we can monitor the heart rate in real time and make sure that exercise intensity is around the target heart rate.

3.2. Heart Rate Detection

An electrocardiogram (ECG) is a graphic tracing of the voltage generated by the cardiac or heart muscle during a heartbeat. It provides very accurate evaluation of the performance of the heart.

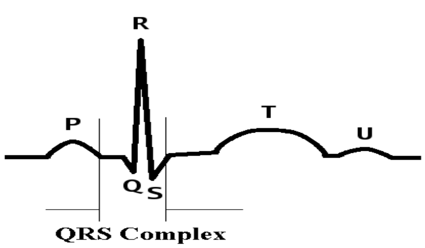


Figure 3: ECG waveform with QRS complex

In order to calculate the heartbeat accurately, the QRS complex must be detected for every beat. The QRS complex is the fast-rising portion of the ECG waveform. We use the high-pass filter to filter samples of the input ECG signal and then the QRS complex can be isolated for every beat. A high-pass FIR filter with a corner frequency of 2 Hz is used. The filtered output is further processed by subtracting a fixed threshold. This cuts off the unwanted disturbances caused by the P and T waves and other movement-related artifacts. Using this method, the QRS complexes are discriminated from the complete ECG waveform. Figure 3 shows a complete heartbeat ECG waveform as input of the heartbeat detection and heart-rate calculation algorithm.

4. Caloric Expenditure with Physical Activities

Physical exercise influences body weight by burning calories. Meanwhile, the physical activity situation can be measured by motion sensor all the time. The MEMS sensors are used to measure the activity calorie consumption with accelerometers by showing the linear relationship between the integrated accelerometer signals and the calorie consumption.

The calories expended for physical activity depend not only on individual weight, but also on the type of activity. The weight of exercisers can be typed into PATHS to estimate the calories expenditure value more accurately. We used the motion sensors to detect different activities automatically, thus PATHS can monitor the caloric expenditure of exercisers in a long term.

The first step in designing a personal fitness plan is to calculate how many calories individual burn in a day. The total daily energy expenditure (TDEE) is the total number of calories that body expends in 24 hours, including all activities. A accurate method for determining TDEE is to determine the basal metabolic rate (BMR), then multiply the BMR by a physical activity factor to calculate TDEE [6].

The Mifflin-St Jeor equation is calorie formula using the factors of height, weight, age and gender to determine BMR [7][8]. This makes it more accurate than determining calorie needs based on total bodyweight alone. The only variable it does not take into consideration is lean body mass. Therefore, this equation will be very accurate in all but the extremely muscular (will underestimate caloric needs) and the extremely overfat (will overestimate caloric needs).

$$BMR = 9.99 \times weight + 6.25 \times height - 4.92 \times age + 166 \times gender) - 161 \quad (2)$$

where *gender* is 1 for males and 0 for females.

We proposed the signal log-energy to estimate the physical activities factor in this study. The log-energy of the step *j* with motion sensor data as follows.

$$E(j)_{\log} = \sum_{i=1}^{N} \log(x_i^2) \quad (3)$$

where j is step number, N is sample size and i is sample number.

5. Implementation and Results

PATHS systems can capitalize on recent technological advances that have enabled new methods for studying human activity and motion, making extended activity analysis more feasible.

The electrical signals generated by myocardium are conducted to the body surface. There is potential difference between different surfaces. After amplifying and filtering, the weak signals of potential difference can be mapped to electrocardiogram. However, compared with very high resistance of human body, the amplitude of electrical signals is very low. ECG signal is vulnerable o electromagnetic environment, in particular embedded 50Hz noises [9]. Thus, the quality of ECG signal relies on amplifier and filter. The high-gain and high-impedance amplifier is used to get accurate signals, and filter is used to get rid of low frequency electromyogram and 50Hz noises. The ECG signal is firstly collected by electrodes, then pass through amplifier and filter, after that the analog signals are converted into digital signals by A/D convertor, and finally processed by Microprocessor.

The accelerometer measurement is used to collect the motion data with SPI interface. The sensor embeds a multi-axis MEMS accelerometer, a digital temperature sensor, power management circuitry and embedded firmware on a single chip. As a result, it provides fully calibrated digital outputs for motion measurements. Embedded signal conditioning and processing eliminates the offset variability of the embedded MEMS sensor, as well as power supply variation.

5.1. Algorithm Implementation

The step detection algorithm was applied directly to the motion data. The original data is filtered to remove the noise at first. Since the running gait frequency is limited in a given range, we use adaptive threshold algorithm with sliding window to detect the running gait frequency. The algorithm scans the whole range looking for the maximum value. If the maximum value is on the central segment and is higher than a threshold, the position is marked as a step and its amplitude is saved as the new threshold. At each new possible step, the threshold is updated, using a linear decay between the previous step amplitude and the current window maximum.

The following simplified steps are required in processing the motion data to estimate the caloric expenditure value:

Step 1: Getting motion data

Step 2: Using low pass filter to remove the noise

Step 3: Segment steps of motion with adaptive threshold algorithm by sliding window

Step 4: Eestimating physical activities factor with $E(j)_{\log} = \sum_{i=1}^{N} \log(x_i^{\,2})$ during each motion step

Step 5: Assessing the activity energy expenditure with multiplying the BMR by a physical activity factor

5.2. Results

System performances are strictly related with the heart rate calculation and physical activities factors estimation algorithms performances. The system sampled at 200 samples per second with 10-bit resolution over a nominal 20 mvolt for ECG signal and 500 mvolt for motion data as input range. The sample values were rescaled after digitization with reference to calibration signals in the original analogue recordings. For the PDA based software, we used eMbedded Visual C++ tools to program. The program shows the ECG waveform and detects the heart rate in real time. Figure 4 shows the software GUI in PDA. The alarm is arisen will if over-training or abnormal rhythms are occurred.

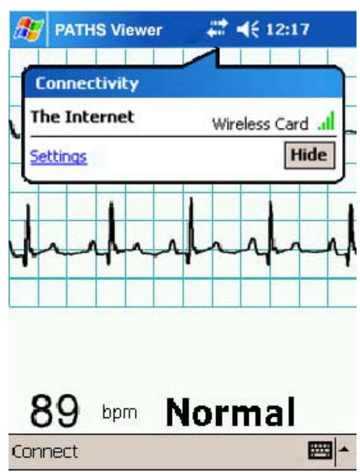
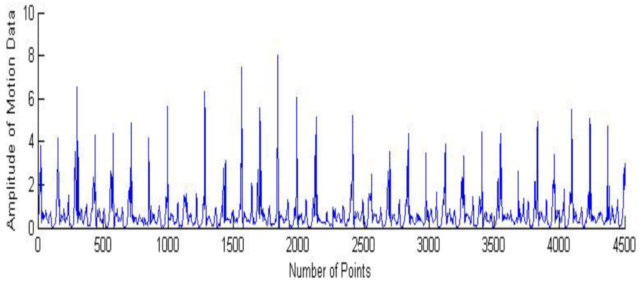
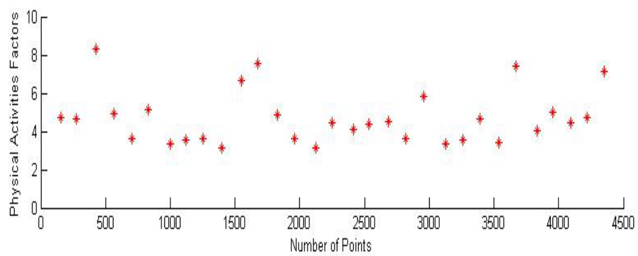


Figure 4: ECG waveform and heart rate detection

The results of physical activities factors for running and cycling motion data respectively are shown in Figure 5 and Figure 6.

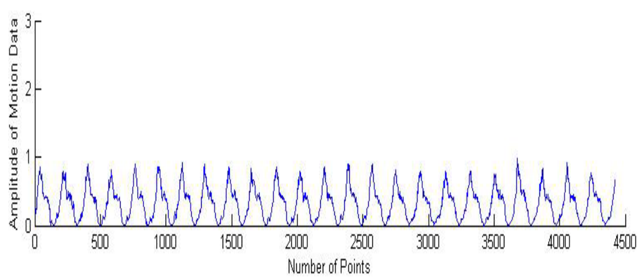


(a) Motion data for running

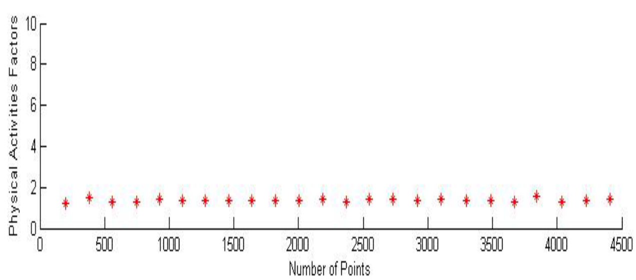


(b) Physical activities factors for running

Figure 5: The results of physical activities factors for running motion



(a) Motion data for cycling



(b) Physical activities factors for cycling

Figure 6: The results of physical activities factors for cycling motion

6. Conclusions

In this paper, we propose a physical activities healthcare system (PATHS) to estimate the exercises intensity and caloric expenditure value with electrocardiogram and motion sensors. The objectives of this system are to help persons to develop individuated suitable physical activity plans and also to assess their fitness level. We evaluate exercise intensity with heart rate calculation and also propose a physical activities factor measurement method to estimate the caloric expenditure. Experiments based on the prototype system show that our system provides an effective solution to estimate and evaluate exercises intensity and caloric expenditure value easily and efficiently.

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