The energy expenditure monitoring system of trail hiking using smart phones

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Abstract

In this study, a mobile-based system for monitoring energy expenditure of the level and gradient walking was developed. A smart phone embedded with GPS and motiondetectors was adopted to detect the locations and altitudes of trail paths for calculating energy expenditure in real-time manner. Unlike other simple applications which cannot be fitted in outdoor environments, the system we designed considers various conditions reported in previous investigations by combining the advantages of smart phones and features of different terrains. The locations and altitudes of a trail were digitized and overlapped on the Google map for trail guiding. The recorded information was then used to calculate energy expenditure for real-time display during hiking. The energy expenditure was calculated based on height, weight, and gender of the user. In order to reduce the computational time, several constants and features were calculated in advance and store in the mobile memory for real-time application. Future studies will focus on improving the accuracy of detecting a location and altitude, especially in the mountain areas.

Keywords: Energy expenditure; Global positioning system (GPS); smart phones; Energy cost of walking; Location based service (LBS)

IV. Introduction

Obese people are suggested to control their weight by managing their calories intakes and energy expenditure (EE). Thus, a lot of tools and approaches have been proposed to measure energy cost more accurately. Although metabolic card, heart rate (HR) monitor, and activity monitor are available to measure EE, they cannot be used ubiquitously. In contrast, a device designed with the smart phone can be carried everywhere at any time with less environment or terrain limitation. Furthermore, smart phone and GPS provide a great opportunity to estimate EE less intensively, non-invasively, and less costly [1].

The measurements of energy cost or energy expenditure (EE) in human and animals have been widely investigated in the last decade. Obesity is becoming a public health problem around the world, especially in the developed countries where people have too much calorie intake. Walking or running on levels or gradients (uphill and downhill), especially on the mountain trails, becomes a popular sport and leisure in Taiwan. It is an effective way to relieve stress as well as to burn extra calories. To estimate and control the EEs of individuals using PDAs (Personal Digital Assistant) or smart phones becomes effective in weight control.

The energy costs of level walking and running have been extensively investigated in [2]. It was reported that the energy cost of level walking depends on the characteristics of the terrain. It is higher on soft than on hard ground [2]. The EE when going uphill increases because the body is working both to produce horizontal movement and against gravity [3,4]. Margaria (1938) evaluated the energy expenditure of men walking on gradients of +/-40%, but he did not develop a predictive equation to calculate EE [3]. Minetti et al. (2002) evaluated the EE of elite mountain endurance racers and proposed an equation to represent their EEs. However, this equation does not explicitly control velocity or involve mass of body with and without carried burdens [2]. Kramer (2010) investigated
the effect on energy expenditure of walking on gradients for adults by considering velocity, body mass, and carried burdens [5].

Heart disease has been listed as the top ranking cause of death in the USA for several years. In Taiwan, it is also a high ranking disease that highly increases the mortality rate. Keeping regular exercise helps people lower their risks in acquiring deteriorating cardiovascular diseases [5]. Hence, people are encouraged to do regular exercise to control their weights and keep their cardiovascular systems healthy. Although a smartphone with GPS seems to be a powerful tool for the measurement of EE, how to elevate and ensure measurement accuracy becomes an important issue. The purpose of this study is to validate the use of a smartphone monitor with GPS data for calculating the EE of outdoor walking and mountaineering, as well as walking at high and low speeds by comparing with the results calculated using the formula proposed in previous investigations [3, 6, 13, 14, 15, 16]. To improve the measurement accuracy of EE, errors including trail coordinates and altitudes, wind resistance, etc., should be eliminated to accurately calculate EE. For example, the errors between previously recorded trail coordinates and the real-time coordinates received when hiking on a mountain trail should be taken into account in calculating the EE.

The structure of this paper is organized as follows. Section II demonstrates the methods and materials used for this study. Experimental results are presented in Section III. Finally, a brief discussion and conclusion is made in Section IV.

V. Methods and materials

A. Subjects

Eight subjects were recruited (four women and four men) from the university located in central Taiwan for this study. The devices used for the experiment include 3 PDAs, i.e., HTC Explorer A310e, HTC Desire HD smart phones, and Acer A100 tablet, each equipped with a GPS. A subject was tested 3-5 times with each device. The testing conditions were slightly different with self-selected velocities for individual subjects. Table I shows the demographic information of the subjects and their normal and fast walking speeds for male and female subjects. The system architecture is depicted in Figure 1.

| TABLE I. DEMOGRAPHIC INFORMATION AND THE WALKING SPEEDS FOR FEMALE AND MALE SUBJECTS |
|-----------------------------------------------|-------------------|-------------------|
| Weight (Kg)            | Female (N=4)      | Male (N=4)        |
| Age (year)             | 48.75±2.98        | 61.25±7.89        |
| Height (cm)            | 22.5±2.8          | 23.75±1.50        |
| Normal velocity (m/s)  | 160.25±5.50       | 172.0±4.6         |
| Fast velocity (m/s)    | 0.94±0.30         | 1.06±0.21         |
|                       | 1.74±0.31         | 1.67±0.26         |

B. Software development

Development of the software depends on the operation system (OS) adopted in a mobile device. In this preliminary study, the Android platform (Version 2.2 or higher) equipped with GPS was used to develop the APP to measure EE for walking on levels and gradients in open areas or mountain trails.

C. Digitization of mountain trails and sample trails

The main objective of this study is to accurately measure the EE for people walking or running in general outdoor environments or hiking on the mountain trails. Ten mountain trails were digitized in Dakang area of Taichung, Taiwan. As shown in Figure 3, a level trail surrounding a sport field was digitized and tested to verify the precision of the developed system. Figure 2(a) shows the slope of a flat path (slope=0) across a sport field in a university campus. In Figure 2(b), the profiles of altitude digitized using different devices or information obtained from an existing database from position A to B are illustrated. The profile digitized with Garmin Dakota 20 adopting...
barometer altimeter is demonstrated to be more accurate than other devices.

As shown in Figure 3 (b) indicates the digitized level trail with a perimeter of 220 meters.

Figure 3 (a) and (b) demonstrates a digitized mountain trail and a level trail, respectively. Altitudes and coordinates (longitudes and latitudes) of individual points of a trail were recorded using GPS tools (Sony GPS-cs1, Garmin Dakota 20 and mobile GPS tracking programs) with a quality better than the GPS system embedded in the mobile phone. In addition to the information recorded with the Sony GPS and Garmin Dakota 20, information provided by the Google map, Garmin Base map and www.geocontext.org was also used for improving the data quality. Before testing the system in mountain trails, a field test was conducted in the sport field of a university campus. The green ellipse shown in Figure 3 (b) indicates the digitized level trail with a perimeter of 220 meters.

As shown in Figure 4, each trail appears as a collection of connected points. In Figure 4 (a), a total of 28 points with an average distance of 3 meters between 2 consecutive points have been digitized. Each point is represented as distinctive features including altitude, longitude, and latitude for location identification, as well as other constants calculated in advance for speeding up the real-time EE calculation, as detailed in Section 2E. Because the coordinate information obtained from current GPS is with great error, even walking along a digitized path needs correction. Figure 4 (b) illustrates how the detected GPS coordinates are corrected to fit the coordinates of the digitized trail.

Figure 4. (a) A line and (b) an elliptical paths
As shown in Figure 5, the trail with 18.21 m long and 7.2 m high as well as a slope greater than 0 is digitized using Dakota 20 (Garmi, UK); whereas the path a subject walking along the digitized path is marked in red. It can be found that a path digitized with a barometer altimeter is more accurate for measuring altitude.

**Figure 5.** A testing trail with a slope greater than 0

### D. Calculation of energy expenditure

As indicated in Eqs. (1) and (2), Minetti (2002) proposed the equations to calculate the EEs in J/(Kg x min) of walking and running, respectively [2]. A running episode is defined as the event with a speed greater than 2.80 m/s [2].

\[
EE_{\text{Minetti}}^{\text{walking}} = 2.5 + 19.6S + 51.9S^2 - 76.8S^3 - 58.7S^4 + 280S^5 \tag{1}
\]

\[
EE_{\text{Minetti}}^{\text{running}} = 3.6 + 10.5S + 46.3S^2 - 43.3S^3 - 30.4S^4 + 135S^5 \tag{2}
\]

Where \(S\) represents the gravity or slope on the trail surface [1,2]. Unfortunately, the above equations do not explicitly control for velocity [3-4]. With regard to walking, in contrast, Ardigo et al. (2003) modified the equation [7], Eq. (1), by using the data of Margaria (1938) to produce an equation which takes the effect of walking velocity into account, as shown in Eq. (3):

\[
EE_{\text{Ardigo}}^{\text{walking}} = 1.966e^{4.911S}5V^2 - 3.773e^{2.416S}5V + 45.71S^2 + 18.905 + 4.456 \tag{3}
\]

In which \(V\) and \(S\) indicate the body mass and slope, respectively. If the conversion factors added to equation involved velocity (\(V\)), body mass of the subject (\(M\)), and the mass of the carried burden (\(M_b\)), the walking energy (Joule) can be modified as:

\[
EE_{\text{walk}} = EE_{\text{Ardigo}}^{\text{walking}} \times M_{t} \times T \tag{4}
\]

where \(M_t = M + M_b\) indicates the total mass and \(T = 0.1\) min (6 sec) is the sampling interval. To consider the effects of wind resistance and sex, the equation developed by Pugh (1970) appears as:

\[
E_{\text{wind}} = 0.00418 \times \frac{0.266(128.1N^24.4\mu_{0.6})}{1m^2} \times 5.057V^2 \tag{5a}
\]

\[
E_{\text{wind}} = 0.00418 \times \frac{0.266(147.4\mu_{4.7\mu_{0.55})}}{1m^2} \times 5.057V^2 \tag{5b}
\]

In which \(H\) is the body height. Therefore, the total energy for walking can be expressed as the sum of the walking energy and the wind resistance energy, as shown in the following equation:

\[
E_{\text{GPS}} = E_{\text{walk}} + E_{\text{wind}} \tag{6}
\]

### E. Data management

In order to speed up the real-time calculation of energy when walking, some values can be calculated in advance and cached in the memory of a mobile phone. For example, some values in Eqs. (3) and (5) can be calculated in advance. In Eq. (3), the constants \(e^{4.911}\) and \(e^{2.416}\) which need more computation time can be calculated and saved as local variables.In addition, the values which need location information, i.e. altitude, longitude, and latitude, can be calculated and saved as additional features for a trail point. Equation (7) shows examples of pre-calculated location-relevant features.

\[
\begin{align*}
\bar{f}_1 &= 1.866e^{4.911S}5V^2 - 3.773e^{2.416S}5V + 45.71S^2 + 18.905 + 4.456 \tag{7a} \\
\bar{f}_2 &= 3.773e^{2.416S}5V + 45.71S^2 + 18.905 + 4.456 \tag{7b} \\
\bar{f}_3 &= (45.71S^2 + 18.905 + 4.456) \times 5.057V^2 \tag{7c} \\
\bar{f}_4 &= 0.00418 \times \frac{0.266(128.1N^24.4\mu_{0.6})}{1m^2} \times 5.057V^2 \tag{7d} \\
\bar{f}_5 &= 0.00418 \times \frac{0.266(147.4\mu_{4.7\mu_{0.55})}}{1m^2} \times 5.057V^2 \tag{7e}
\end{align*}
\]

In which \(\bar{f}_1\) and \(\bar{f}_2\) indicate the body mass and slope, respectively. If the conversion factors added to equation involved velocity (\(V\)), body mass of the subject (\(M\)), and the mass of the carried burden (\(M_b\)), the walking energy (Joule) can be modified as:

\[
EE_{\text{walk}} = EE_{\text{Ardigo}}^{\text{walking}} \times M_{t} \times T \tag{4}
\]

where \(M_t = M + M_b\) indicates the total mass and \(T = 0.1\) min (6 sec) is the sampling interval. To consider the effects of wind resistance and sex, the equation developed by Pugh (1970) appears as:

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\]

\[
E_{\text{wind}} = 0.00418 \times \frac{0.266(147.4\mu_{4.7\mu_{0.55})}}{1m^2} \times 5.057V^2 \tag{5b}
\]

In which \(H\) is the body height. Therefore, the total energy for walking can be expressed as the sum of the walking energy and the wind resistance energy, as shown in the following equation:

\[
E_{\text{GPS}} = E_{\text{walk}} + E_{\text{wind}} \tag{6}
\]
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\[ EE_{\text{dr}} = f_1 V^2 - f_2 V + f_3 \quad (8) \]
\[ EE_{\text{wind}} = f_4 V^2 \quad (9a) \]
\[ EE_{\text{wind}} = f_6 V^2 \quad (9b) \]

F. Applications of GPS and accelerometer

Most of the outdoor navigation and location-based mobile applications are based on GPS and additional sensors. GPS is more accurate in outdoor than indoor environment. Even if it is currently the most popular approach, there are several possible sources of errors, such as canyon effects in urban environments, delays of the GPS signals in the ionosphere and troposphere, etc. [8]. Figure 4 (b) shows an example of localization errors during outdoor walking.

In the proposed system, GPS data are received from the satellite every second. However, the right position of a subject cannot be recognized because of induced errors. Therefore, the trail information was stored in the local database. When walking along a designated trail path, the location which is closest to digitized trail is obtained by the 6 consecutive points received from the GPS. To distinguish still from moving activity, detectors including accelerometer and gyroscope are used to detect motion [9].

The algorithm is described as follows:

Step 1: Retrieve digitized GPS information of a trail. For example, the green dot path shown in Figure 4 (b).

Step 2: Determine the closest location on the digitized trail by averaging the 6 consecutive points received from the GPS. For example, the blue dot path shown in Figure 4 (b).

Step 3: Detect the motion with accelerometer and gyroscope embedded in the mobile phone.

Real-time location-based tracking applications require continuous calculations and transmissions of GPS and motion detector data, which consume a considerable amount of the phone’s battery [10]. Hence battery management is an important issue. In order to reduce battery power consumption, the sampling intervals of GPS data and motion detector are set to 1 and 6 seconds, respectively. If the a still (not-moving) event has been detected, the GPS will be turned off automatically to save battery power.

G. Real-time calculation of EE

In order to display the aggregated consumed calories, real-time calculation of EE is needed when walking or hiking. In the proposed system, the EE is displayed every 6 seconds, although the interval of 15 seconds was suggested by another investigation [1]. As shown in Figure 4(a), a detected trail location is displayed as a point. For example, points 1, 2, 3 and 4 indicate that a subject moved from point 1 to point 4 in 6 seconds. The EE calculation must be considered in every point or location, because the slope is calculated based on 2 consecutive points. Figure 6 shows the flowchart of calculating the EE. Figure 7 demonstrates the graphical user interface of the designed system.

VI. Experimental Results

The subjects were asked to carry out 3 tests by walking along the trail using 3 PDAs. They were asked to walk in normal speed (<1.5 m/s) during the first and third tests in fast speed (>1.5 m/s), while the subject walked in a mixed mode with self-adjusted normal and fast speeds in the second test. The slope of the trail is within the range from -0.1 to +0.1. Table II shows the velocity and EE of male and female subjects. The average speed of all the subjects is 1.39±0.47 m/s, whereas the average speed is 1.4±0.38 and 1.38±0.5 m/s for male and female, respectively. The average EE for male and female are 5.6±1.62 and 4.3±1.5, respectively. The average EE for all subjects is 4.68±1.61 Kcal/min. The average speed under normal and fast speed modes are shown in Table III. Table IV depicts the average EE in two different velocities for male and female, respectively.
I. Discussions and Conclusions

This development aimed to measure energy expenditure for people hiking in open areas and mountain trails in Dakun area of Taichung city. In this preliminary study, only walking on the level trail was tested to verify the usefulness of the designed system. As shown in Table II, it was observed that women might be more difficult than men in losing weight if walking at the same distance, because women consumed lower energy than men.

Table II. Measured energy expenditure (Kcal/min) and velocity (m/s).

<table>
<thead>
<tr>
<th></th>
<th>Normal velocity</th>
<th>Fast velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>5.60±1.62</td>
<td>4.30±1.50</td>
</tr>
<tr>
<td>Female</td>
<td>4.30±1.50</td>
<td>4.30±1.50</td>
</tr>
<tr>
<td>Pooled</td>
<td>4.68±1.61</td>
<td>4.39±0.47</td>
</tr>
</tbody>
</table>

Table III. Average velocity of normal and fast walking speeds.

<table>
<thead>
<tr>
<th></th>
<th>Normal (m/s)</th>
<th>Fast (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>1.06±0.21</td>
<td>1.67±0.26</td>
</tr>
<tr>
<td>Female</td>
<td>0.93±0.29</td>
<td>1.73±0.31</td>
</tr>
<tr>
<td>Pooled</td>
<td>0.96(0.28)</td>
<td>1.71 (0.3)</td>
</tr>
</tbody>
</table>

To compare our data with the results reported in previous literature [6,11,12,13,14,15]. As shown in Table V, it can be observed that the estimated EEs in this study are very similar to the data calculated based on the formula proposed in previous investigations with an overestimation of 1.43%-16.54%. On the other hand, our result is higher than most of the previous data (3.36%-9.23%) except the data predicted by McArdle (-6.93%) [11] and Van Der Walt (-11.33%) [12].

Table V. Comparisons between the result obtained in this study and the calculated values obtained from formula of previous investigations.

<table>
<thead>
<tr>
<th>Method</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our data</td>
<td>5.60</td>
<td>4.30</td>
</tr>
<tr>
<td>ACSM [13]</td>
<td>4.93(12.03%)</td>
<td>4.16(3.36%)</td>
</tr>
<tr>
<td>Leger[14]&amp;Pandolf [15]</td>
<td>4.80(14.29%)</td>
<td>4.04(6.00%)</td>
</tr>
<tr>
<td>McArdle [11]</td>
<td>5.37(4.14%)</td>
<td>4.60(-6.93%)</td>
</tr>
<tr>
<td>Van der Walt [12]</td>
<td>5.52(1.43%)</td>
<td>4.79(-11.33%)</td>
</tr>
<tr>
<td>Hall [6]</td>
<td>4.67(16.54%)</td>
<td>3.90(9.23%)</td>
</tr>
</tbody>
</table>

There are several limitations appeared in this study. First, the GPS cannot obtain precise altitudes and locations during trail walking. This will induce significant error during real-time EE monitoring because the calculated velocity and gradient are quite different from the real values. The altitude information obtained from the Google map and other online tools (http://www.geocontext.org) is with great error. Thus, a more precise instrument is needed to digitize the altitudes of the trails.

The advancement in mobile communication and its wide-spread use open up the opportunities for developing mobile healthcare systems, which facilitates...
e-health applications at home or outdoor environment. In this study, we developed a mobile-based system of for estimating the EE using smart phones. The preliminary results demonstrate the feasibility in using a smartphone for the management of energy expenditure. However, more efforts, such as noise reduction of GPS, external memory expansion, efficient memory utilization, inclusion of more healthcare-relevant parameters, functions for creating users’ own trails, and more efficient management of battery power, should be focused. Furthermore, we will consider to add other outdoor events, such as running, cycling, and other functions to our system. In addition, the system will also integrate with the function for managing calorie intake so that the net energy intake can be obtained by considering both calories intake and calories expenditure.

In conclusion, in this preliminary study, a mobile-based system for monitoring energy expenditure of trail walking has been developed by integrating the GPS and motion detectors. Computational time, battery power management, and memory management were also considered for the fulfillment of real-time monitoring and elongation of battery usage. Future studies will focus on improving the accuracy of detecting location and altitude, especially in the mountain areas.

REFERENCES
