31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Footpaths: Fusion of mObile OuTdoor Personal Advisor for walking rouTe and Health fitnesS

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***Abstract*— This paper is mainly concerned with the integration of wireless body sensor network and walking route navigation system in order to provide the most suitable walking path to the wearer following the wearer's health condition. A novel system called *Footpaths* is proposed. Footpaths is designed to facilitate the measurement of the user's cardio-respiratory fitness level (CRF), through the use of a wearable wireless sensor network, in which the result is used as a key factor in determining the most suitable walking route. The CRF is assessed based on the maximal oxygen uptake or VO2max through field performance tests (i.e. Rockport 1-mile test). The prototype of Footpaths and showcase of its effective uses are exhibited in the paper.**

I. Introduction

RECENT Recent emergence of miniaturized wireless body sensor devices has offered a bright future for ambulatory patient monitoring. These wireless body sensor devices are programmable and capable of sampling, processing, and communicating one or more vital signs such as heart rate, blood pressure, oxygen saturation and activity, or environmental parameters including temperature, humidity and light [1]. These sensor devices are attached on the human body and interact with a sensor node, which acts as a gateway, and this condition is commonly known as Wireless Body Area Network (WBAN).

We are very much concerned that more than one quarter of population in the developed countries suffers from cardiovascular disease or CVD [2]. In Singapore alone 32.3% of deaths are caused by CVD, and Ministry of Health statistics show that for each year, the number of deaths from cardiovascular related diseases is on the rise [3]. Considering this, elderly folk or people who just suffered from cardiac arrest or heart attack are generally not recommended to do activities that may stress their heart functions [4]. Even normal walking is an activity that may overburden the heart especially when the road surface is uneven. A short route may not be the best way for the user to take when considering his/her heart status. It is however, insensible to disallow them from carrying out their daily outdoor routines, such as walking to the market or food stores. To address this significant issue, we propose *Footpaths* - a mobile personal advisor for walking route based on the user's cardio-respiratory fitness level. Footpaths resides in a mobile device and is capable of measuring the user's cardio-respiratory fitness level using a network of wearable body sensors.

Footpaths incorporates four novel features, namely: (*i*) Mobile cardio-respiratory fitness test, (*ii*) Real-time walking/running activity monitoring with accurate speed detection and distance tracking, (*iii*) Mobile walking route advisor based on the user's cardio-respiratory fitness level, and (*iv*) Terrain-aware navigational system. Each of these features including Footpaths prototype is described and showcased in this paper.

This work was supported by Science and Engineering Research Council (SERC) of the Singapore Agency for Science, Technology and Research (A*Star) on Embedded & Hybrid Systems II (EHS-II) programme under grant 052-118-0058.

II. Related Work

Walking route navigation system has been a continuing topic of interest, and the most recent highlight is the release of Google maps walking routes [5]. Google maps provides the shortest walking route from point A to point B, and the user simply specifies his/her location and destination address through its online geographical map. Others like proposed by Kawamura [6] concerns with a mobile service that supports elderly people wishing to go out and promotes their participation in social activities was proposed. This system collects information on the existence of nearby barriers and provides information to users via a mobile phone equipped with GPS.

Yamazaki [7] reports the work on a Footprint-based Ambient Navigation System called AshiNavi. AshiNavi is an indoor walking navigation system. It navigates user with walking footprints displayed on the user's walking path. The footprints are overlaid on the floor on which the user is actually walking, so that the user may get to his/her destination by just stepping on the footprints.

Another walking route navigator is proposed by Kaminoyama [8]. In this system, the walking navigation system is developed based on photographs for early stage people with dementia. The system provides a photograph of the landmarks to the mobile device.

We have noted that the existing walking routes navigation systems mainly focus on finding the shortest path for the user regardless of a user's health condition. These systems, although useful, may not be appropriate for the elderly or people with heart problems, especially when the suggested route crosses uneven terrain. Our proposed system (Footpaths) addresses this issue as presented in the remainder sections of this paper.

III. Footpaths: A Novel Walking Navigation System Based on User's Fitness

Footpaths adopts VO2max as an indicator of a person's cardio-respiratory fitness level (CRF). VO2max stands for maximal oxygen uptake and refers to the amount of oxygen our body is capable of utilizing in one minute. The units are: *ml O2/kg-min* or milliliters of oxygen per kilogram of body weight per minute. It measures the capacity of the heart, lungs, and blood to transport oxygen to the working muscles and measures the utilization of oxygen by the muscles. VO2max is considered as the most accurate indicator of cardio-respiratory fitness [9]. Accurate measurement of VO2max generally requires the collection and analysis of inhaled and exhaled gases during exercise to exhaustion. This is usually done in a lab environment, and should be under the supervision of professionals. Unfortunately, this type of testing is not widely available to the general public and may not be appropriate for people with serious heart problems. With Footpaths, we are able to measure the VO2max of the user anytime and anywhere without the need to go through a stress test, and store the VO2max trend and other relevant information in the user's profile. VO2max is the key element in determining the most appropriate walking route to take. This route may change overtime as the person's fitness level improves.

Footpaths consists of two main components namely; (*i*) cardio-respiratory fitness evaluation, and (*ii*) walking route advisor. Each of which is described in the following:

A. Cardio-respiratory fitness evaluation

For this evaluation, Footpaths requires two accelerometers and one ECG sensor device. The two accelerometers are attached to the user's left and right leg and the ECG sensor is worn on the arm with its two-leads attached to the chest. Footpaths communicates with these sensor devices wirelessly. There are three elements involved in this evaluation: (a) walking speed estimation, (b) heart rate detection scheme, and (c) cardio-respiratory field test procedure.

- *Walking speed estimation*

The Extended Kalman (EK) filter is employed to provide an accurate estimation of the flexion angles of the human body. We are utilizing dynamic filtering technique to tracks the thigh flexion angle of the human body. The activity is classified as movement activity if both thighs are swinging in opposite direction. The real-time determination of the walking speed is derived from the fact that force exerted by an object is directly proportional to the acceleration, and thus physical activity intensity will be a function of acceleration. Walking speed may be obtained from a nonlinear mapping of the average kinetic energy experienced by both thighs.

Our study on the walking speed estimation was conducted on five test subjects running on a treadmill at speeds progressively increasing from 1 km/h to 13 km/h, depending on their physical fitness. The results of our estimated walking speeds gave an overall Mean-Square Error (MSE) of 0.91 $(km/h)^2$. Further details on this study can be found at our earlier report in [10].

- *Heart rate (HR) detection scheme*

Our heart rate detection scheme is carried out from the point when new ECG data packets arrive. Firstly, the R-peak position from these data is determined. Based on this position, we are able to find the QRS position and QRS trace back position, which are needed to determine the R-R interval. The R-R interval is subsequently utilized to determine the heart rate value based on equation (1) and the value is then displayed on the application.

$$HR = \left(\frac{60000}{RR - \text{interval}} \right) beats / \min \qquad (1)$$

- *Cardio-respiratory field test procedure*

The Rockport 1-Mile Walk Test Procedures is used initially as the basis of our test procedure (readers are referred to [9] for further details of Rockport). Rockport is useful for those who are unable to run because of their low fitness level and/or injury. The user should be able to walk for 1 mile or 1.609km to complete this test. The procedures of this test are as follows: (*i*) one mile walking distance and gets the exercise HR above 120 bpm, (*ii*) at end of the walk, check the recovery HR (one minute after the test ends), (*iii*) calculate the VO2max, and (*iv*) find the fitness level accordingly. The VO2max (mL kg-1 min-1) is calculated from equation (2):

$$\text{VO2max} = 132.853 - (0.1692 \text{ x } Weight) - (0.3877 \text{ x } Age) + (6.315, \text{ for men}) - (3.2649 \text{ x } Time) - (0.1565 \text{ x } HR) \qquad (2)$$

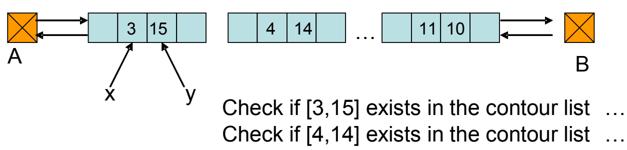
Weight is defined in kg, *Age* is in years, the *Time* relates to the total time to cover 1 mile in nearest hundredth of a minute (i.e. 15:42 = 15 .7 [42/60= 0.7]), and the *HR* corresponds to recovery HR in bpm.

When deployed, Footpaths monitors the walking/running speed of the person as well as the heart rate while ensuring the test procedures is performed properly. At the end of the test, Footpaths computes the final VO2max values, maps it into a percentile and stores it as an indicator of the fitness level of the person. During the test, Footpaths may also store the heart rate signals for caregivers to further analyze the user's cardio fitness.

B. Walking route advisor

The walking route advisor utilizes the Global Positioning System (GPS) function in the mobile device to locate user's location and his/her destination point (Footpaths can only be operated in GPS-capable mobile devices). To determine walking paths, Footpaths takes into consideration several parameters including user's location, destination, and land contour. A simplified geospatial analysis is part of the process. In this case, we assume that the geographic and contour map is available digitally, which can be obtained using a geospatial software such as one deployed by [11]. Having known the user's current location as well as the desired destination specified by the user, Footpaths is able to automatically determine the possible walking routes from the user's current location to the specified destination through the use of Dijkstra algorithm [12]. In order to advice the user on the best path to take, Footpaths would need to consider user's fitness level (V02max) which is measured following the test procedure as described earlier.

Once the walking route options are determined, Footpaths defines a bounding box that is able to enclose all of the suggested routes and overlays a contour map within the bounding box. Each contour line on the contour map is converted to its equivalent x and y coordinate position within the bounding box and stored in a contour list. Footpaths then traces through each of the route options to determine where the routes intersect with the x and y coordinates of the contour lines. Any intersection of the route line and the contour line is marked and at the end of each route option trace. With the possible routes identified, the system traces each route and determines the number of intersections with the contour lines.



For instance, in Fig. 1 we have a walking route from point A to point B. Between these two points is the location coordinates to reach B from A. Each of these coordinates is counter-checked to find whether these intersect with any contour lines as given in the contour list.

Three phases are defined to determine the hardest or easiest route to traverse. To illustrate these, we use two routes, A and B as an example in the following.

- *First Phase*: Cluster detection is performed to determine if clustering of contour lines take place along the suggested route. This is the main deciding factor as the cluster corresponds to the steepness of the terrain.

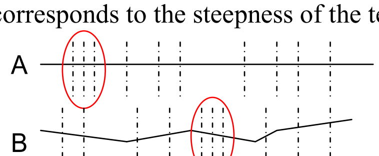


Fig. 2. 1st phase – cluster detection

Fig. 2 shows the same frequency and intensity of cluster detected for the two routes. In our case, we consider cluster intensity has a higher weightage than frequency.

- *Second Phase*: If the first phase has equivalent result, then we count the number of crosses between the individual route and the contour lines. This is the second deciding factor. The less number of intersections, the easier the route is. Fig. 3 illustrates this second phase whereby each route comes across the same number of intersections.

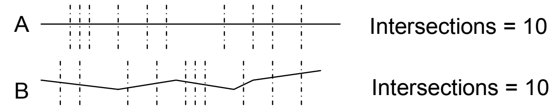


Fig. 3. 2nd phase – number of intersections

- *Third Phase*: Going through the first and second phase, if the results remain the same, we apply the last phase. In this case, the distance of the route is divided by the number of contour lines crossed to determine the average distance between contour lines. From Fig. 4, we can see that route B is the easier route to traverse than A.

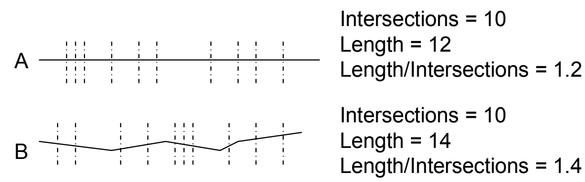


Fig. 4. 3rd phase – average distance per contour intersection

Footpaths then splits the Rockport 1-mile test percentile (10th percentile to 90th percentile) into various segments, depending on the number of route options from the user's location to his/her destination. For example, if there are three walking routes, the percentile from 10th percentile – 90th percentile is split into 3 segments. Each of these segments is assigned one of the walking routes based on their difficultly level such as the lowest segment (lower percentile of VO2max score) is given the easiest route, while the highest segment (higher percentile of VO2max score) may be given the harder route.

IV. Footpaths Prototype and Application

This section shows the initial prototype of Footpaths and demonstrates its general uses. For the sensor devices, we utilize two accelerometers and one ECG.

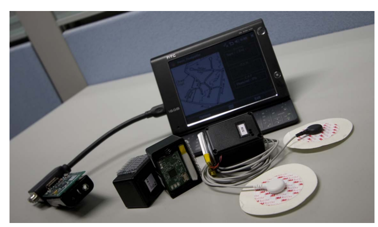
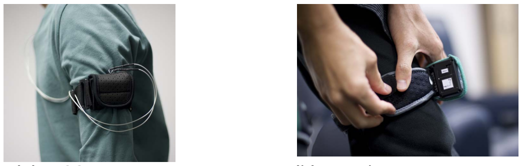


Fig. 5. EHSII Sensor Nodes and PDA

These sensors are called EHSII sensors, developed by the Embedded and Hybrid Systems II programme in A*STAR [13] which have similar specifications as the Imperial College BSN motes [14]. The gateway resides in the PDA (HTC X7501 Advantage Ultra Mobile). Fig. 5 shows the sensor nodes and the mobile device used for the prototype. The following illustrates the proposed Footpaths use cases:

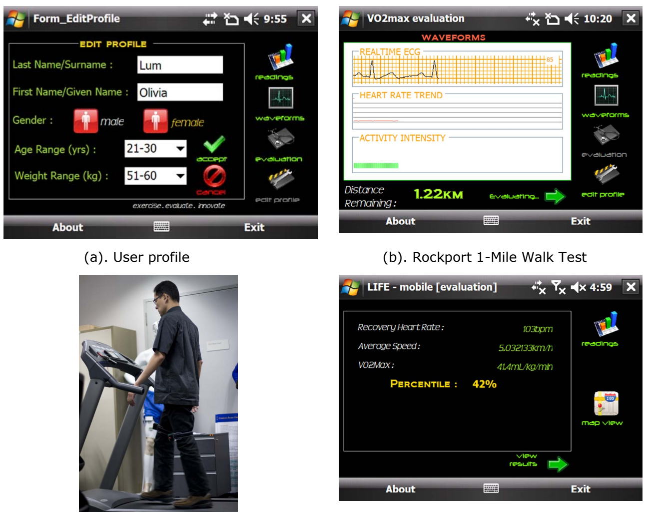
Step 1: Wearable sensors - ECG sensor is worn on the chest (Figure 6(a)) and accelerometers on each thigh (Figure 6(b)).



(a). ECG sensor (b). Accelerometer sensor

Fig. 6. ECG and accelerometer sensor placement

Step 2: Inputs the user profile (Fig. 7(a)). Executes Rockport 1-Mile Walk Test (Fig. 7(b)) – at this point, user starts walking (Fig. 7(c)) and the remaining distance is shown. At the end of the test, VO2max result displayed on the screen (Fig. 7(d)).

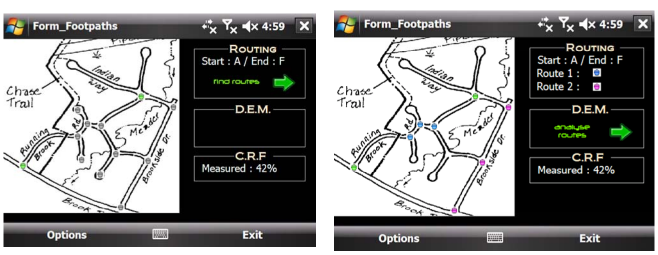


(a). User profile (b). Rockport 1-Mile Walk Test

(c) User walking on a treadmill (d) VO2max percentile result

Fig. 7. Cardio-respiratory fitness evaluation process

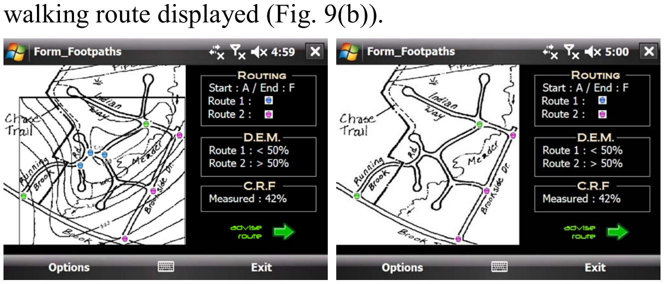
Step 3 : User selects a start and end point on the map, and the alternatives routes are displayed as shown in Fig. 8(a) and (b), respectively.



(a). Starting and end point (b). Option of routes are determined

Fig. 8. Destination location and routes alternative

Step 4 : Contour information in the immediate vicinity is taken into consideration (Fig. 9(a)), and final personalized walking route displayed (Fig. 9(b)).



(a). Contour map overlaid (b). Recommended route displayed

Fig. 9. Contour map integration and route recommendation

As can be seen from Fig. 9, there are two routes available to the selected destination. Footpaths recommends the longer route after considering the person's CRF (<50%) and the contour information of the route.

V. Conclusion and Future Work

In this paper, we have presented a preliminary work on Footpaths, a novel walking navigation system based on user's fitness level. Footpaths is a step towards a more heart-healthy society. Its novelty and innovative aspects lie in its revolutionary use of a patients' CRF result fused with terrain Information to determine a walking route that is optimized to his/her fitness level.

For future work, we shall look into different approaches to measure user's fitness level in real-time. We are especially considering Bayesian network scheme to analyze and estimate the user's health fitness.

References

[1]. D. Estrin, et al., "Next Century Challenges: Scalable Coordination in Sensor Networks," In *Proc. 5th Ann. ACM/IEEE MobiCom*, pp. 263–270, 1999.

[2]. D. T. Jamison, "Investing in Health", In Disease Control Priorities in Developing Countries, 2nd ed., *Oxford University Press*, 2006.

[3]. Singapore Health Foundation [Online]. Available at: http://www.myheart.org.sg. Last accessed: April 2009.

[4]. PA Ades, "Cardiac Rehabilitation and Secondary Prevention of Coronary Heart Disease", *New England Journal of Medicine*, 345: 892-902, 2001.

[5]. Google map's walking routes [Online]. Available at: http://googlesystem.blogspot.com/2008/07/google-maps-tests-walking-directions.html

[6]. T. Kawamura et al, "Mobile Navigation System for the Elderly – Preliminary Experiment and Evaluation", In *Proc. of Ubiquitous Intelligence and Computing*, pp. 578–590, 2008.

[7]. Yamazaki, et al, "AshiNavi: A Footprint-based Ambient Navigation System", In *Proc. of Pervasive Computing Workshop on Pervasive Display Infrastructures, Interfaces and Applications*, 2007.

[8]. H. Kaminoyama et al, "Walk Navigation System Using Photographs for People with Dementia", In *Proc. of HCI*, LNCS 4558, pp. 1039–1049, 2007.

[9]. American College of Sport Medicine, "ACSM's Health-Related Physical Fitness Assessment Manual", Second edition, *Walter Kluwer*, 2008.

[10]. W.S. Yeoh, I. Pek, Y.H. Yong, X. Chen, and A.B. Waluyo, "Ambulatory Monitoring of Human Posture and Walking Speed Using Wearable Accelerometer Sensors," In *Proc. of 30th IEEE EMBC*, 2008, pp. 5184–5187.

[11]. Digital Data Services, Inc [Online]. Available at: http://www.usgsquads.com/. Last accessed: April 2009.

[12]. E. W. Dijkstra.," A note on two problems in connexion with graphs", In *Numerische Mathematik*, 1: 269–271, 1959.

[13]. Embedded & Hybrid Systems II (EHSII), A*STAR [Online]. Available at: http://www.ehs-sg.org/. Last accessed: April 2009.

[14]. B. Lo, S. Thiemjarus, R. King, and G-Z. Yang, "Body Sensor Network – A Wireless Sensor Platform for Pervasive Healthcare Monitoring," In *Proc. of the 3rd International Conference on Pervasive Computing*, 2005, pp.77–80.