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PPCare: A Personal and Pervasive Health Care System for the Elderly

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***Abstract*—Over the past decade, the ageing of population has increasingly become a serious social issue all over the world. Accordingly, the market demand for health care monitoring of the elderly has greatly emerged. However, existing health care systems yet cannot provide convenient and comprehensive health care services for the elderly. This paper presents a mobile phone based personal and pervasive health care system for the elderly to monitor their daily life and physiological indexes. The whole system consists of four major functions, including sport planning, calories consumption estimation, fall alert and physiological indexes monitoring. PPCare system has been deployed and applied to the elderly in two communities for trial use and some constructive feedbacks have been collected for further system improvement.**

Keywords-health care; activity recognition; step counting; calories estimation; physiological indexes monitoring

I. INTRODUCTION

Population ageing [1] which denotes the trend and process of the elderly population growth of a country or area has gradually become a serious social problem all over the world. A widely used definition of ageing society, often attributed to the United Nations, is one in which the 65+ group accounts for more than 7% of the total population. An alternative definition looks at the 60+ set. If they make up 10% or more of the population, the country is deemed an ageing society. According to the sixth census of China in year 2010, the population of 60+ group has reached 178 million, which accounts for 13.26% of the total population [2]. And population aged 65+ reached 119 million which accounts for 8.87%. China has become an ageing society since year 2000, and over the past decade the process of ageing has been accelerated. Furthermore, according to Chinese government reports, the empty-nest elderly family accounts for more than 50% in small-sized city and countryside, and 70% in some large and medium-sized city in year 2011, respectively. In year 2010, the population of disabled elderly has reached 33 million, which accounts for 19.0% of total population of the elderly. Due to the increasingly serious situation of the elderly, the market demand of elderly health care services grows accordingly. The health care system is the integration of people, institutions, and resources to deliver health care services to meet the needs of target population. However, current health care systems cannot meet the need of the elderly to provide convenient and remote health information monitoring services for both elderly people and their guardians.

Up to now, there exist several health care systems such as LifeGuard [3], StepCounter [4], iFall [5] and jWotch [6]. The LifeGuard system was developed for monitoring the health of astronauts to ensure their safety during space flight and extravehicular activities and to monitor their physiology during exercise routines. However LifeGuard is a complex system with various wearable devices and is designed for astronauts. It does not hold for the elderly. The Nokia Corporation has developed a StepCounter application which utilizes the mobile phone's internal accelerometer to detect user's walking and calculate user's total daily steps and distance. Then the StepCounter could estimate the daily calories consumption to provide scientific advices for user's sports. The iFall is a low cost android application for fall detection and alerting. It makes use of the smart phones' internal 3-axis accelerometer and detects the fall event through a threshold-based fall detection algorithm. The jWotch is a kind of high-tech mobile phone watch which integrates mobile phone, watch, location, alerting module and health data detection function. The jWotch is embedded with a cardiovascular data collection sensor which can analyze 35 kinds of cardiovascular parameters that play an important role on heart disease, hypertension, hyperlipidemia and myocardial infarction. These systems just focus on one aspect of health field respectively. The elderly needs a relatively convenient and comprehensive system.

In this paper we designed and developed the PPCare system. PPCare is a low-cost integrated system, which is comprised of a server, a smart phone and three kinds of medical sensors, for the elderly to monitor their daily life and physiological indexes including activity, sport time, step count, calories consumption, fall, blood oxygen concentration, heart rate, blood pressure and fat content. The entire system has four major functions which are sport planning, calories consumption, fall alert and physiological indexes monitoring. The sport planning helps the elderly to make plan of their movement according to their historical statistical movement data. The calories consumption function estimates the elderly's energy consumption of movement and can be considered as the reference of their diet. The fall alert function could give an alert when the elderly fall and send a short message to their guardians. The physiological indexes monitoring function utilize some external medical sensors to monitor the elderly's physiological information and can be considered as their health reference for doctors to provide rational suggestion.

II. PPCARE SYSTEM

A. Architecture

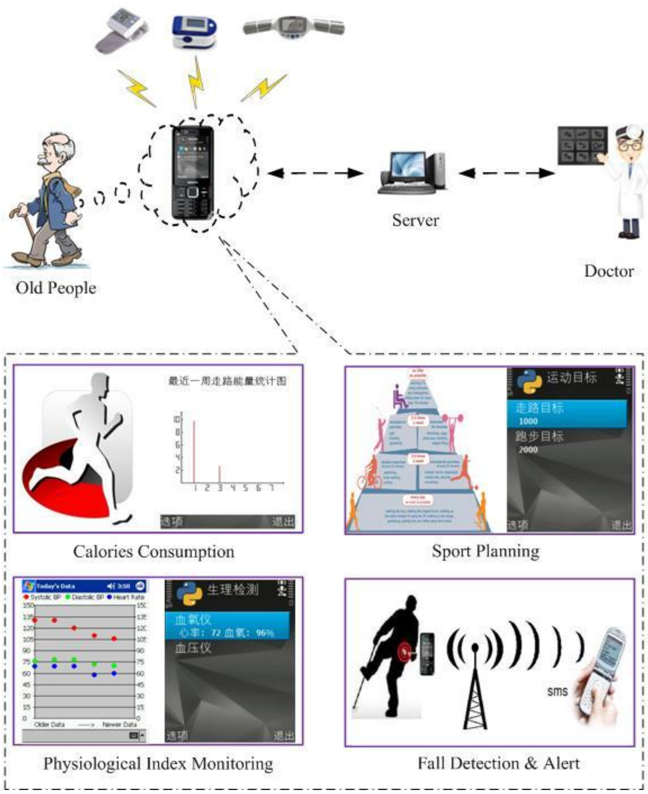

Figure 1. Architecture of PPCare

As shown in Figure 1, the system consists of four parts, i.e., old people, client (smart phone and medical sensors), server and doctor.

We use the Nokia N82 phone as the mobile platform because we can develop the system using Python [7] on it rapidly. The Nokia N82's OS is Symbian S60 3rd edition and it has an embedded 3-axis accelerometer running at about 36Hz. The phone supports sending and receiving SMS messages and a GPS receiver is embedded as well. We use an ordinary PC as our server to storage user's health information. SQL Server 2000 is selected as our database toolkit. The system supports three kinds of external medical sensors to sense user's physiological indexes. These medical sensors are HC-801 pulse Oximeter, HC-502 Blood Pressure Monitor and HC-301 Body Fat Analyzer produced by ETComm Corporation [8]. All these devices support communication via Bluetooth®2.0 standard.

As shown in Figure 1, the old people use smart phone to monitor their health information in their daily lives. The corresponding information will be uploaded to the server automatically every day. If an old person needs professional health suggestion, he can send a request to our system. Then, his health data will be summarized and sent to the doctor in an anonymous way. The doctor will reply some advices to the old person after analyzing the data.

B. System Function

1) Sport Planning

Sport planning helps the elderly to manage their movement. When using the system at the beginning, users can set the goal of their movement including exercise magnitude of walking and running. The system will automatically recognize user's activities including stationary, walking and running. The start time and the end time of each activity are also recoded. Additionally the system will count user's walking and running steps respectively. Users can view the statistical data of their movement such as steps completed today, the remaining steps, steps of last week and steps of last month. A statistical chart can be shown for users to observe their movement trend.

2) Calories Consumption Estimation

Calories consumption estimation helps the elderly to find out their energy consumption. The system utilizes a medical calories consumption formula to figure out the calories consumption of user's movement. The statistical data of calories consumption such as calories consumption of today, last week and last month is also available to users. The calories consumption trend can also be viewed in an individual statistical chart.

3) Fall Alert

The system integrates a fall detector. The user can choose to turn on or turn off the fall detection function. If it is running and a fall just occurs, the system will alarm loudly and show a dialog box to ask whether he really has a fall or not. If no response received in 15 seconds, the system will send a SMS message to the elderly's guardian. The phone number of guardian can be stored in the system preliminarily. The SMS message describes the fall event and contains the occurrence location provided by Google Geolocation API and Google Map API.

4) Physiological Index Monitoring

The elderly highly concern about their physiological indexes. The system can connect to the medical sensors via Bluetooth®2.0 for real-time physiological data display and storage. The data will be uploaded to server for long-term health analyzing.

III. METHODS

A. Activity Recognition

Activity recognition is one of core components for the system to provide movement management. The PPCare system recognizes three everyday activities in real-time, i.e., stilling, walking and running. We use the 3-axis accelerometer data to implement activity recognition. [9] has explained why accelerometer data can be used to infer human's physical activity. Also as mentioned in [9] and [10], Decision Tree classifier is found to achieve the best recognition accuracy with low computational complexity, therefore we choose Decision Tree as the classification algorithm in our PPCare system.

To achieve the high accuracy of activity recognition, following steps below should be performed:

1) Raw Data Collection

We use Nokia N82 phones to collect accelerometer data. The N82 phone has a build-in accelerometer which is a tri-axial MEMS motion sensor (LIS302DL) produced by STMicro. The acceleration output data rate of the sensor is 100Hz or 400Hz; however we can get acceleration data with merely sampling frequency of approximately 36Hz by calling the Python for S60 API.

We have collected activity data from 4 subjects by performing staying at a place (standing or sitting), walking and running respectively. All of the accelerometer data was labeled with the specific activity. To achieve this procedure, we develop a Python script and execute it on N82 phone to collect accelerometer data.

2) Calibration & Normalization

Because of drift of sensitivity and offset on every axis of triaxial accelerometer, the calibration is needed to assure the accelerometer data quality and get accurate readings in terms of *g*-force [9]. Calibration is a one-time process and not needed to be performed in real-time. Let $a = (a_x, a_y, a_z)$ be a vector of raw accelerometer returned by the PythonForS60 API, and $g = (g_x, g_y, g_z)$ denotes a calibrated vector measured in g ($g = 9.8\, m/s^2$). Let K_x, K_y, K_z and b_x, b_y, b_z be the estimated respective sensitivity gains and offsets of triaxial accelerometer. We have the following Eq.(1) to get the real value of *g*-force:

$$g_{axis} = K_{axis} * a_{axis} + b_{axis}, \text{where } axis = x, y, z. \quad (1)$$

We calculate K_{axis} and b_{axis} by putting the phone on the table at positive and negative g along relevant axis. For example, let (a_1, a_2, a_3) and $(a_1', a_2' \, a_3')$ as the positive and negative *g* reading along X-axis, we can calculate K_x and b_x as Eq.(2) and Eq.(3):

$$K_x = \frac{2g}{(a_1 - a_1')}, \text{where } g = 9.8 \quad (2)$$

$$b_x = -\frac{K_x * (a_1 + a_1')}{2} \quad (3)$$

In our system a_1 and a_1' is 300 and -290 respectively, so K_x and b_x is figured out to be 0.332 and -0.1661. The computing of K_y, b_y, K_z, b_z is similar to K_x and b_x.

The calibration parameters K_x and b_x are used for accelerometer data normalization. After normalization, the raw accelerometer data is converted to accurate acceleration data in terms of *g*-force.

3) Selecting a Proper Sliding Window

Activity is a motion in a time span, and a single acceleration data is just an instantaneous value which can never be used to infer a person's activity. We must use a sliding window and consider the whole window as a sample of a kind of activities. Because the sampling frequency is approximately 36Hz, we choose 128 as the sliding window size which represents almost 4s time span.

4) Moving-average Filtering

To reduce the effect of noise, we should use a moving-average filter of span L to smooth the data. After selecting L as 5, a new series of readings are generated for feature extraction.

5) Feature Extraction

The raw data is too large to be processed and is suspected to be well-known redundant. It contains both irrelevant information and noise, therefore it is hard to use a classification model directly on the raw data set. In order to get the useful information and eliminate the irrelevant information, we should extract features from the raw data set. To recognize the daily activities, we select four motion features as follows for Decision Tree training:

- Mean. The mean value of acceleration data represents the DC component of the motion signal.
- Standard deviation. The standard deviation represents the acuteness of motion which can distinguish the three kinds of activities.
- Mean Cross Rate. The rate denotes the number of acceleration curve crosses the mean value of acceleration which can describe the fluctuation extent of activity data.
- Spectral peak position. The spectral peak position represents the frequency of the major periodic signal component which can be used to distinguish between walking and running.

6) Classification

We use Decision Tree as our classification model and the generated tree is shown in Figure 2.

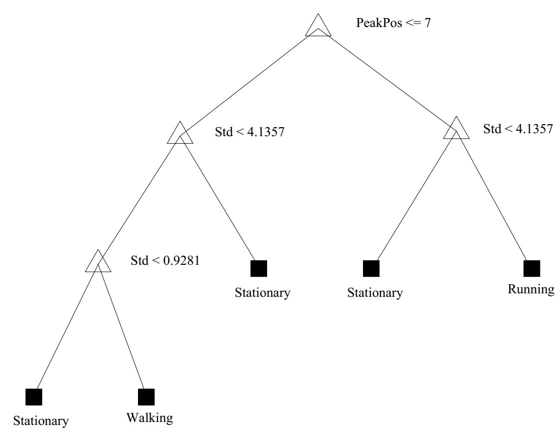

Figure 2. Decision Tree generated from the extracted features.

There are only two selected parameters in the decision tree, so it has low computational complexity to recognize the user's activity.

7) Recognition

The last step for activity recognition is just to read the data from the mobile phone in real-time and preprocess the data following step 1~5. Then just using some if-else statements can determine the user's activity.

B. Step Counting

Step counting is another core component for system to provide movement management. We consider walking and running as a periodic movement, so the acceleration should be periodic as well. The method of footsteps detection we used is similar to the algorithm mentioned in [11], i.e., counting the peaks in the variance of acceleration.

To detect footsteps, the system reads the input data in real-time and normalizes the data to real value of g-force, then calculates the variance over sliding windows of 0.15s. In our system it is approximately five samples in a sliding window. Then Median filtering is used to eliminate the effect of noise. After median filtering, we calculate the variance of the sliding windows and a new data series is generated. Finally, we read data from variance series one by one and then consider the peak data whose difference value from the former valley and the latter valley are both greater than a threshold as a step of one activity. If a step is detected, increase the counter of walking or running steps according to the current activity result from activity recognition.

C. Calories Consumption Estimation

We use the formulas mentioned in [12] to estimate calories consumption. The total calories consist of three parts, i.e., calories of stationary, walking and running. The total calories are computed as Eq.(4):

$$Calories = 5.01 * VO2 \tag{4}$$

Where, parameter value 5.01 is a conversion factor and the $VO2$ represents the oxygen consumption. The $VO2$ contains three parts as Eq.(5):

$$VO2 = R + H + V \tag{5}$$

Where, R represents the oxygen consumption when the person is resting. For non-resting activity, the oxygen consumption consists of horizontal and vertical components. H represents the horizontal component and V represents the vertical one. R is computed as Eq.(6):

$$R = 3.5 * Weight * Time/1000 \tag{6}$$

For computing H and V of waling and running, the factor is different:

For walking activity:

$$H = 0.1 * speed * Weight * \frac{Time}{1000} \tag{7}$$

$$V = 1.8 * speed * Weight * \frac{Time}{1000} * grade \tag{8}$$

For running activity:

$$H = 0.2 * speed * Weight * \frac{Time}{1000} \tag{9}$$

$$V = 0.9 * speed * Weight * \frac{Time}{1000} * grade \tag{10}$$

Where, $Weight$ is the user's weight in kg and $Time$ is the time duration in each activity. The computation method of $grade$ is shown in Figure 3:

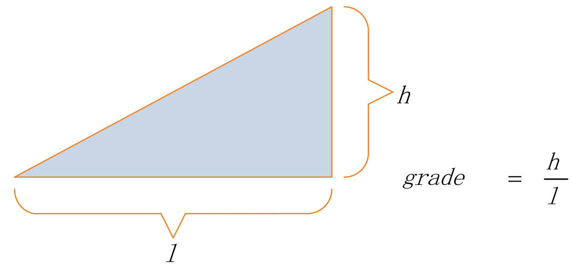

Figure 3. Computation method of $grade$.

The $speed$ is computed as Eq.(11):

$$speed = K * height * avg\_steps\_per\_second \tag{11}$$

Where, K is a constant factor of value 0.415 for male and 0.413 for female, respectively. The $height$ is provided by user and $avg\_steps\_per\_second$ is computed through steps count dividing by time. Because in our system we do not consider the vertical direction movement, we just need to calculate the R and H in Eq.(5).

D. Fall Detection

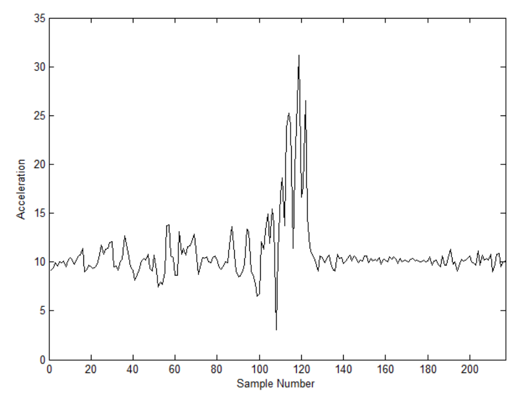

Figure 4. A typical fall acceleration curve.

A typical fall acceleration curve is shown in Figure 4. The fall process consists of two periods. The first is the free fall period in which the acceleration's amplitude will drop significantly below 1g. The second is the fall stop period in which the person has a collision with the ground and the acceleration's amplitude will reach the highest value.

We use four thresholds to determine a fall. If the amplitude of acceleration crosses the lower and upper thresholds in the presetting duration period, then a fall is suspected. In our system the lower threshold is set to 0.5g and the upper one is set to 3g which is similar to the iFall [5]. The duration is set to 0.25s~1s which is given by our experiment.

E. Physiological Index Monitoring

Before monitoring, the user should wear and turn on the sensor, and then the system will connect with the sensor via Bluetooth. For HC-801 Pulse Oximeter the system should send a message to start it and then the output data will be received. For HC-502 Blood Pressure Monitor and HC-301 Body Fat Analyzer, the system will receive the data after direct connection. The HC-801 Pulse Oximeter, HC-502 Blood Pressure Monitor and HC-301 Body Fat Analyzer are shown in Figure 5.

(a) (b) (c)

Figure 5. (a)HC-801 Pulse Oximeter, (b)HC-502 Blood Pressure Monitor and (c)HC-301 Body Fat Analyzer.

IV. SYSTEM APPLICATION

We have deployed and tested the system in Er Tiao community and Qian Yong Kang community in Beijing East District and invited more than 60 elderly persons to try out PPCare system.

(a) (b)

Figure 6. Our PPCare System application in (a)Er Tiao community and (b)Qian Yong Kang community in Beijing East District.

The scene of PPCare system application and test site is shown in Figure 5. Firstly, we explained the function of the system to the elderly and then the elderly had a try to use the system. We also leave some devices to the elderly for a long-term use. All the elderly completed a questionnaire and some of them give constructive suggestions to us.

From the statistical result of the questionnaire, we found one third of the respondents are male. 48% of the respondents live with their children and the rest live alone or with their mate, which is consistent with the government reports. Almost all the elderly thought that PPCare system is practical for them and they are willing to use it. At the same time, one of the elderly thought the system is too complex to use.

V. CONCLUSION AND FUTURE WORK

Our PPCare system has integrated activity recognition, step counting, fall detection, calories estimation and physiological indexes monitoring together, to provide health care services for the elderly. The traditional systems have implemented only one of the functions and cannot provide a relatively comprehensive service. The wide usage of smart mobile phone makes it possible for users to use it at anytime and anywhere.

The power efficiency problem of the smart phone is a serious topic because the accelerometer must keep working on read the acceleration data. However, when user is stationary, it is not necessary for system to detect step and fall. We can build a model for the system to stop the accelerometer and start it intermittently when user is stationary. Currently the system is developed on Symbian using Python. The decrease of the market demand and terrible user experience of the platform limit the application of the system. So we plan to develop a duplicate of the system on other platform such as Android and iOS. Due to the low sampling frequency of the accelerometer on N82 phone, the step detection is not very accurate. How to use the accelerometer of smart phone to achieve precise step counting is another future work to do. Additionally we will also extend some new functions to the system, such as analyzing users' keystroking information to infer their ability of cognizance, etc.

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