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Towards a Context-Aware Biofeedback Activity Recommendation Mobile Application for Healthy Lifestyle

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Abstract

In this paper, we propose a mobile application that provides users with physical activity recommendations on a daily basis. The increasing percentage of physical inactivity among individuals [1] is the main motivation behind this system. Thus, this system represents one possible solution to counter this issue by recommending the minimum threshold of daily physical activity required for individuals to maintain an active lifestyle. The system performs this task by utilizing a biofeedback sensor (accelerometer) that tracks user's movements. Users' calorie consumption is calculated from acceleration data and is then used as a foundation for system recommendations. Also, context data is utilized to provide context- aware recommendations, which will make the suggested activities from our system easier to follow for individuals. The proposed system gives recommendations in the forms of textual, audio and haptic recommendations. A questionnaire has been conducted in order to estimate the importance of the proposed system through estimating participants' daily activity levels. Additionally, it aims to determine context data that can support the proposed system most fully. Results upheld the proposed system with 46% of participants who exercise for less than 15 minutes daily. Our findings also show that weather conditions and work commitments are the factors, which have the strongest negative impact on an individual's physical activity.

Keywords: Physical ctivity recommendation; biofeedback sensors; context-aware data

1. Introduction

Nowadays, physical inactivity has been ranked fourth in the list of leading risk factors for global mortality, causing 6% of deaths globally [2]. According to World Health Organization (WHO) statistics, in 2008 about 31% of adults (28% of men and 34% of women) all over the world aged 15 or older were not sufficiently active [1]. Moreover, around 3.2 million deaths occurred yearly due to physical inactivity, which is defined as a lack of physical activity [1]. Moreover, statistics state that physical inactivity is evaluated as the main cause of many severe health conditions. Approximately 21–25% of breast and

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colon cancers, 27% of diabetes and 30% of ischaemic heart disease burden cases are caused by physical inactivity [2]. Therefore, the increase in the levels of physical inactivity globally, including high, middle and low-income countries, is noticeable [1]. As a result there is an urgent need to motivate people to increase their physical activity level in order to promote their well-being, as well as reduce the risk of non-communicable diseases. But the question remains, how can we motivate these people to increase their physical activity level? The solution that we suggest here is motivating them by recommending the minimum requirement of daily physical activity that will guarantee their well-being, taking into account a user's current situation and the conditions of the surrounding environment. Mobile computing technology can be employed to serve this purpose since it enables resource sharing and data transportation among computers or other smart devices such as smartphones [3]. Smartphones are currently considered one of the most efficient tools to achieve such a task. In addition to be a communication tool, smartphones play multiple roles in the lives of users, such as being a tool for organization and entertainment. Consequently, developing a mobile activity recommendation application that aims to increase physical activity level for users by utilizing their smartphones is a promising solution to minimize physical inactivity since smartphones accompany users most of the time.

In order to provide suitable recommendations, activity recommendation systems need to be sensitive to the current situations of users and their surrounding environments. As a result, utilizing a user's context is an essential factor for providing proper recommendations. Fortunately, smartphones are currently equipped with features that facilitate acquiring context data. However, a user's context data is not sufficient to provide personalized activity recommendations that aim to increase their physical activity level. Tracking physiological changes in a user's body is another essential factor to personalize the provided recommendations. Although this task is very crucial in physical activity advisory system, it is not considered in the existed systems. Biofeedback technology is an optimal technique to accomplish this task, which is tracking physiological changes in user's body and sending them to the system in a synchronous manner. Biofeedback technology is an optimal technique to track these changes and feed the system in a synchronous manner. It is a consistent field that specializes in tracking, measuring, evaluating and transferring the physical attributes of the human body, such as heart rate and blood pressure, to a peripheral device in order to broaden the knowledge of these attributes and facilitate the responding process to their changes [4]. It deploys various sensors, which represent information sources, to provide critical information about physical conditions of the human body as a result of the continuous tracking [5].

In this paper we propose a system, which will provide personalized physical activity recommendations for users by considering calorie burned and context information while maintaining the user's preferences regarding physical activities and locations. These recommendations will contribute to the promotion of a healthy lifestyle by providing important health benefits, including the prevention of weight gain, as well as the prevention of lifestyle related diseases such as heart disease.

The paper is organized as follows: Section 2 presents related works. The proposed system, with a detailed description of each part and how it works, is presented in Section 3. Section 4 will present the work in progress. Finally, Section 5 provides the conclusion and a discussion of future work.

2. Related work

In this section, we present some examples of researchers that use biofeedback sensors and context data in the physical activity domain. Accelerometers are considered one of the most efficient sensors and are used heavily to provide vital data about users' physical activities in a continuous manner.

The work of researchers in [6] is a well-organized effort, which studies accelerometer usage to track and measure physical activities. They provide a summary of best practices and research recommendations

regarding the use of an accelerometer in physical activity. This summary is the result of a comprehensive study of nine scientific papers, formal responses from experts measuring the physical activity domain, and extensive discussions with researchers as well as manufacturers. It ends up minimizing the knowledge gap regarding the use of the accelerometer to measure physical activity behaviour. It also includes best practice recommendations which focus on the five main areas of accelerometer usage which are: accelerometer selection, quality, and dependability, accelerometer use protocols, accelerometer calibration, analysis of accelerometer data, and integration with other sources of data.

The survey in [7] is a practical example of using an accelerometer to measure physical activity in large-scale studies. This survey aims to characterize the physical activity levels of the United States (U.S.) population represented in three age groups (children, adolescents and adults) using an accelerometer. Measurements provided by accelerometers helped researchers discover several important findings. This includes getting the same results regarding the gender and age patterns of activity when objective and subjective measures of physical activity are performed.

Counting calories is one of the popular applications that depend on biosensors to determine energy consumption levels, which is strongly related to physical activity level. Researchers in [8] presented a method to calculate daily energy consumption for users by using a 3-axis accelerometer available in a mobile phone handset. They used acceleration data to infer users' posture, which in turn mapped to specific Metabolic Equivalent of Task (MET) value. According to the MET's values and users' postures, calorie expenditure is estimated. They demonstrated the accuracy of their application by comparing the result to reference devices (SenseWear and Polar). Another group of researchers designed a Wellness Wear System containing biosensors to capture bio-signals of the human body such as Electrocardiographs (ECG) [9]. They also presented a calorie tracker application running on an Android system that utilizes ECG data, which is acquired from the Wellness Wear System to provide a weight loss program.

Regarding the use of context data in the physical activity field, there are several researchers that use different types of context data to improve physical activity levels. One of the recent researchers in this area is the work found in [10]. A mobile application called Motivate has been developed to provide personalized advice based on contextual data such as weather, the user's location, and agenda. Researchers aim to improve the user's behaviour regarding physical activity by suggesting simple advice on a daily basis. They conducted a user study on 25 Android phone users in order to evaluate the implemented application. Motivate system sent 3556 messages and 47.8% of the messages gained positive responses from participants. Thus, system evaluation shows the potential of Motivate application to improve physical activity level of its users. However, even with agenda setting, system evaluation results show that half of sent messages were refused by receiving negative responses from the user because of sending the advices in an inappropriate time in addition to bad weather. Moreover, the system needs manual interaction from user's side representing in setting agenda on daily basis for helping the system to perform its task, which adds more responsibilities on the daily tasks for a user, which in turn may drives the user to avoid using the system.

So, we can notice from this review that on one hand, the existing systems which provide biosensor data such as number of calories burned as a feedback to show how active the person is, did not attempt to provide useful advices or recommendations for the users in order to improve their physical activity level such as system in [8], which may leads to minimize the great benefit of biosensors values and limit their role to be a tool to notify a user about his/her current status without any tangible action to improve these values. On the other hand, the existing systems, which provide physical activity advices or recommendations to the users in order to increase their activity level, provide general and not personalized advices, which may not be suitable for users' physical conditions, commitments or preferences such as system in [10]. Also, they did not provide a feedback that reflects user's physical

activity level in addition to requiring a manual interaction with the system in order to perform its task [10].

Thus, in order to overcome the disadvantages of the previously mentioned systems, we developed our system that combines biofeedback feature with context data to prove the potential of the combination in improving physical activity level of users. It is developed in a form of mobile application that sends an appropriate advice in the suitable time and encourages the user to follow the advice by mentioning the number of calories burned compared to the target number of calories that must be burned daily for living in a healthy lifestyle. A detailed explanation of the proposed system is in the following section.

3. The proposed system

3.1. Feasibility study

In order to evaluate the feasibility of the proposed system, and whether it will be useful to develop it as a mobile application, we conducted a feasibility study on a random sample. 28 individuals aged 20 to 59 years old participated in the study. 46% of participants reported they typically exercise for less than 15 minutes daily, whereas 25% said they don't exercise on a daily basis. Additionally, daily exercise for a period of between 15 to30 minutes or for a period of between 30 to 60 minutes per day was applicable for 14% of respondents for both categories. Thus, it is possible to say that the majority of participants do not exercise for a period that meets the minimum recommended threshold of daily physical activity required for promoting health and preventing diseases related to physical activity. The minimum recommended threshold is continuous or discrete 30 minutes of moderate activity per day according to American Heart Association (AHA) [11], Centers for Disease Control and Prevention (CDC) [12] and WHO [13]. In fact, 64% answered No whereas 36% answered Yes when we asked explicitly whether they met this recommended threshold. Regarding contexts that have the most negative impact on the physical activity level of participants, weather conditions ranked first at 23%. Other contexts ranked as follows: calendar (18%), person's mood (18%), work environment (14%), location (9%), the person's weight (6%) and health conditions (5%). Also, we asked participants if they would agree to attach biofeedback sensors to their bodies in order to track energy consumption and their answers were: Yes (68%), No (14%) and Not applicable **(**NA) (18%). From the previous results, we were able to determine the proposed system structure, which will be presented in the following section.

3.2. System structure

The proposed system, which is illustrated in Figure 1, consists of five main components, which includes the biofeedback sensors, context component, data storage component, activity recommendation
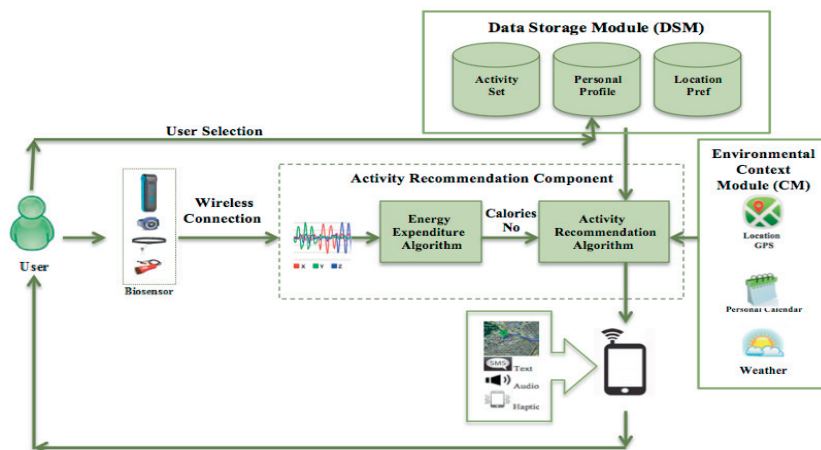

Fig. 1. System structure

component and user interface. The description of these compounds is as follows:

- *Biofeedback Sensors:*
  Biofeedback sensors such as the ECG or the accelerometer are attached to users' bodies in order to track and capture biological signals such as heart rate or acceleration data. Next the collected signals are transmitted wirelessly into the activity recommendation component. Wi-Fi or Bluetooth technology can be used as a wireless connection method.
- *Context Component:*
  Based on the feasibility study results mentioned above, we selected weather, personal calendar and current location as context data sources.
- *Data Storage Component:*
  This consists of three main data storages, which are: activity set, personal profile and location preferences. Activity set data storage contains a set of activities, such as walking and running, mapped to their METs values which are considered a reference to provide suitable activities for users' context based on their preferences. Personal profile contains users' personal data, such as name, weight and selection history, which are essential to provide recommendations because, for instance, the recommended amount of energy consumption differs according to the individual's weight. This amount of energy is measured in calories.
- *Activity Recommendation Component:*
  This consists of two main algorithms. The first is the Energy Expenditure Algorithm, which calculates energy consumption according to the collected biological signals from the user's body. The outcome of this algorithm, which is provided in the number of calories, is fed to the second algorithm, which is the Activity Recommendation Algorithm, which represents the core of the proposed system. The Activity Recommendation Algorithm completes its task by retrieving data from the data storage component and the context component. It then provides contextual activity recommendations based on user's energy consumption, context and preferences.
- *User Interface:*
  This system is designed to deliver recommendation messages in three different forms: text, audio and Haptic. Text recommendations appear on the mobile screen, whereas audio recommendations start simultaneously when the recommendation is triggered. The haptic feedback appears both in the form of vibration in the smart phone and in a chair where the user is seated.

3.3. How does the system work

Before explaining how the proposed system works, it is important to mention the basic values that we refer to in order to build the Activity Recommendation Algorithm.

- *Reference Values:*
  As mentioned above, physical activity exercise for 30 minutes daily is considered the minimum threshold for maintaining body wellness and maintaining a healthy lifestyle. However, some specialists recommend 60 minutes per day for optimal health results [14]. According to [14], an individual needs to perform physical activities that last for 60 minutes per day in order to promote health and prevent lifestyle related diseases. Also, these activities must be at intensity of 3 Metabolic Equivalent of Task (METs). According to [15], it is defined as the total energy consumption of the physical activity. In fact, there are standard

tables of pre-defined METs values for several physical activities with different intensities for each activity, such as the tables found in [14]. Table 1 shows walking as an example of a physical activity with different METs values that reflect different intensities, in addition to other examples [14].

Table 1. Examples of physical activities with corresponding METs values

Physical activity	MET value
Walking with normal pace	3.0
Walking down the stairs	3.0
Walking with moderate pace	3.3
Fishing	3.0
House cleaning	3.0
Weight lifting	3.0
Bowling	3.0
Volleyball	3.0
Walking at a brisk pace	4.0
Bicycling (outdoor)	4.0
Bicycling using a stationary ergometer	4.0
Swimming	6.0
Shovelling snow by hand	6.0
Climbing the stairs	8.0
Running	8.0

- *Generating activity recommendations:*
  In order to provide proper recommendations, the system begins by determining the optimal calorie number that the user needs to burn daily through physical activities. The energy consumption algorithm used in [16] is used for this purpose and it is represented by the following formula:

  Energy (kcal) = 1.05 × METS × Weight (kg) × Exercise Time (h)   (1)

Thus, according to the reference values mentioned in the previous subsection, METs substituted by 3 and Exercise Time substituted by 1 for 60 minutes per day. Then, the system provides activity recommendations after repeatedly checking for the current calorie consumption of the user, and comparing it with their optimal calorie consumption. After each recommendation the system stores user's choices for future reference in order to determine preferences regarding physical activities. Furthermore, when the user reaches or exceeds their optimal calorie consumption number, the system encourages the user using text or audio (or both) and stores this result for future reference too. The algorithm is shown in Figure 2.

In order to estimate the potential of the proposed solution, we monitored the physical activity level of one subject for three business days before and after applying the algorithm in an off-line manner. The monitoring results are shown in Table 2. It is noticeable that the number of activity calories improves after applying the algorithm. The number of activity calories, which results from performing physical activity, such as walking or running, is compared to the total number of calories. This represents the whole energy consumption out of biological and physical movements burned per business day, which

starts at 9:00 a.m. and ends at 5:00 p.m. The average percentage of activity calories to total calories is 3.85 % before the algorithm and 14.04% after it, which considers promising results to prove the efficiency of the proposed solution. A Fitbit Ultra activity tracker has been used for this task [17]. It contains a built-in accelerometer that tracks user movement and provides different information, such as number of calories burned, steps taken, distance and floors climbed. As well, Fitbit provides the means for developers to access and utilize collected data in their applications [17].

Algorithm 1 Activity Recommendation Algorithm

Inputs: c_u, user's calendar; w, current outside weather; l_u, user's current location
  w_u, the user's weight;
  $ccal_u$, the current number of calories burned for the user;
  AC, set of activities used as a reference

Outputs: RA_u, set of recommended activities for the user according to the context and calories consumption;

  1. **Determine user's optimal daily energy consumption ($ocal_u$) :**
     $ocalu = 1.05 \times 3 \times Weight (Kg) \times 1$
  2. **Check number of consumed calories every 1 hour and check user calendar**
     Read $ccal_u$;
     if $ccal_u < ocal_u$
     While $ccal_u < ocal_u$
     Begin
       if (c_u = appointment)
         { **calculate Distance** $D_{(x,y)} = x - y$;// x appointment location and y user's location
          for i ← 1 to n ; // n number of activities in AC
         if (w)
         {
            $AC_u = i_{type=outdoor}$;
            calculate Time $T_{(x,y)} = D_{(x,y)}$ / Activity Speed;
            calculate $NCT_{(x,y)}$ = $1.05 \times MET \times Weight (Kg) \times (T_{(x,y)} /60)$;
            Display RA_u ;
            Store user selection;
         }
         }
       else
       {
          Switch Cases: (w & l_u & c_u) // for each case:
          for i ← 1 to n ; // n number of activities in AC
          {
             Create AC_u;
             Calculate NCT = $1.05 \times MET \times Weight (Kg) \times T$;
             Display RA_u ;
             Store user selection;
          }
       }
     End
     else
     {
       if ($ccal_u = ocal_u$)
       { **Display** "Congratulations! You reach your goal today to burn <$ocal_u$> calories";
          Store DayDate in the system history;
       }
       else
       { **Display** "Awesome! You exceed your goal today by burning extra <$ccal_u - ocal_u$> calories";
          Store DayDate in the system history ;
       }
     }
  3. **End of Algorithm**

Fig. 2. Physical activity recommendation algorithm

Table 2. Monitoring results of activity calories for Subject 1:

Day	Before		After	
	Activity calories	Total calories	Activity calories	Total calories
1	121	2391	311	1878
2	92	2385	273	1999
3	191	1882	236	1981

4. Conclusion and Future work

This paper proposes an activity recommendation application. It features the deployment of a biofeedback sensor, which is an accelerometer, and the context data in order to give suitable recommendations for users in the right time and location. It aims to promote a healthy lifestyle and minimize the inactivity level of its users. This system differs from existed systems in the fact that it considers user's physiological conditions represented in the amount of calories burned to calculate the optimal amount of calories that must be burn daily and provide recommendations according to this calories amount and the environment context data, too. The system structure is presented with a detailed description of its parts and their functions. Additionally, a recommendation algorithm and reference values are presented. A monitoring experiment is conducted to track the activity level of one subject before and after applying the algorithm in an off-line manner. The experiment's results are promising and it shows the potential benefit of the proposed system. We still working on application development and testing it on several subjects so we can evaluate the system in a formal way and prove it's positive impact on the user's activity level.

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