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Mobile cloud-based physical activity advisory system using biofeedback sensors

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HIGHLIGHTS

- Use biofeedback and environmental context data to provide personalized physical activity advice.
- Use mobile cloud technology to store and process the proposed system's components.
- Evaluation results reflect the positive impact of the system on individuals physical activity level.

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ABSTRACT

Physical inactivity has gained a wide attention due to its negative influence on human wellness. Physical activity advisory systems consider a promising solution for this phenomenon. In this paper, we propose a mobile cloud-based physical activity advisory system utilizing biofeedback sensors and environmental context data based on calories expenditure from performing various activities by tracking user's physical movements. To evaluate the proposed system, we conducted in total a three-month experiment on six users. For each user, we tracked the amount of burnt calories from the physical movements for a two-week period. During the first week, the system did not send any advice, while during the second week, the system was advising the user on activities to perform. The compared results of the two weeks collected data (without and with advice) reflect the positive effect of the proposed system on participants' physical activity level. The system motivates them to reach or exceed the recommended number of calories to be burned daily.

1. Introduction

Wellness is one of the broadest concepts that are used consistently for characterizing the quality of a human's life. Physical wellness is defined as the active and continued effort towards maintaining an optimum level of physical activity, nutrition, self-care, and healthy lifestyle actions [1]. Physical activity plays a critical role in a healthy lifestyle and several current statistics support this role. According to recent statistics of the World Health Organization (WHO), physical inactivity ranked as the fourth leading risk factors for adults' mortality globally since it causes 6% of deaths [2]. Numerically, It is the reason behind around 3.2 million deaths occurred annually [3]. Specifically, WHO stated that about 31% of adults (28% of men and 34% of women) all over the world, aged 15 and over, were not sufficiently active [3]. In addition, physical inactivity has been evaluated as the main cause of severe diseases according to many studies. For instance, it causes around 27% of diabetes cases, 30% of ischemic heart disease burden cases, and approximately quarter of breast and colon cancers cases [2]. Researchers are trying to address this problem by developing systems that motivate people to increase their physical activity level taking into account their current conditions and environmental context.

According to the American College of Sports Medicine (ACSM) [4], the American Diabetes Association (ADA) [5], the American Heart Association (AHA) [6], Centres for Disease Control and Prevention (CDC) [7] and WHO [8], the minimum recommended threshold is a continuous or discrete 30 min of moderate intensity physical activity on daily basis. Moderate intensity physical activities are defined as activities that have Metabolic Equivalents of Task (METs) values ranges between 3–6 METs [9]. MET value

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of the physical activity describes the rate of energy expenditure, which is calculated by measuring the oxygen uptake and carbon dioxide production [10].

On the other hand, the Institute of Medicine (IOM) recommends 60 min per day of moderate intensity physical activity [11,12] in order to maintain a healthy lifestyle. Similarly, the authors in [13] recommend 60 min of Leisure-Time Physical Activity (LTPA) per day at intensity of 3 METs for achieving optimal health results. LTPA is defined as activities that a person performs during free time according to personal needs and preferences. Moreover, CDC has proven that three 10-min short bouts are as efficient as one 30-min bout [7].

To measure the required amount of energy to perform a specific physical activity, we need to consider the MET value of that activity. The MET value for a specific activity is calculated through two steps. First, exercise or activity metabolic rate is estimated by measuring oxygen uptake and carbon dioxide during an exercise activity and by taking into account the body mass and its unit is mL kg^{-1} min^{-1}. Then, the resulted activity metabolic rate is divided by a standard resting metabolic rate which is 3.5 mL kg^{-1} min^{-1}. Another unit to express the MET value for a specific activity is kcal kg^{-1} h^{-1} and in this case a MET equals 1 kcal kg^{-1} h^{-1} [10].

To motivate a given user to perform some physical activities, we need to consider several factors, which are user's physiological status and life commitments, surrounding environment conditions, solution's accessibility and mobility in addition to the need to be a user friendly solution. Thus, knowing the user's context is an essential factor to achieve healthier lifestyle. Nowadays, acquiring environmental context data is enabled by smartphones as they are equipped with many sensors that facilitate this task [14]. Although detecting user's surrounding conditions is beneficial, it is not yet sufficient to provide personalized activity advice that aims to increase user's physical activity level. We still need to capture biological features that reflect the current status of user's body. Although this factor is critical in a physical activity advisory system, it is not considered in most of existing systems.

Biofeedback technology [15] is defined as a field that uses specific sensors and specializes in tracking, measuring, evaluating, and transferring the physical attributes of the human body, such as heart rate, walked steps, blood pressure and different body posture [16], to a peripheral device. This field aims to capture these physiological changes in real-time and unobtrusive manner [17]. Some examples of the used sensors are pedometers, accelerometers, and heart-rate monitors. Currently, there is a wide range of products available commercially for tracking user's physical activity that use accelerometers. Nike Fuel Band [18] and Fitbit Ultra [19] are examples of such products. In addition to off-the-shelf sensors, smartphones are meanwhile equipped with accelerometers and gyroscopes that can be deployed efficiently as a source of valuable data that reflect user's current movement and direction continually which help to detect users' behavior and daily habits [20].

According to [21], smartphones are placed in the front line of beneficial mobile devices to serve healthcare field for several reasons. One of them is pairing standard features such as voice and text communications with advanced computing and communication facilities such as Internet access. Currently, a broad range of various applications such as fitness and lifestyle management apps and chronic disease management apps have been developed and used effectively [22]. However, mobile phone applications faced and are still facing major challenges such as storage capabilities. Fortunately, cloud computing emerged to overcome mobile storage and power obstacles and when combined with mobile computing, it forms a powerful unified concept called Mobile Cloud Computing (MCC), which delineates the features of future mobile applications. According to [23], the main concept of MCC is transforming the data storage and processing capabilities outside the mobile device to integrate the cloud features into the mobile environments [24].

The main contributions of this work can be summarized as follows:

- Design and development of a mobile cloud-based system called CAB, which stands for Context Aware Biofeedback that utilizes the amount of calories burned to promote the user to perform physical activities. This system follows the general architecture of mobile cloud computing applications mentioned in [23] and its biofeedback feature is built based on the U-biofeedback reference model for ubiquitous biofeedback systems [15].
- Design and development of a physical activity advisory algorithm that is stored and running in the cloud: by utilizing the concept of calories burned through performing different physical activities, this algorithm provides physical activity advice to the users while considering the environmental context and the user's physiological status. It is designed to provide an advice that represents the daily-recommended threshold for maintaining a healthy lifestyle, which is continuous or discrete 60 min of moderate intensity (3–6 METs) activity per day.
- Evaluate the proposed system by conducting a relatively long time experiment on six users, which lasted for three months by testing each user for a two-week period.

The rest of this paper is organized as follows. Section 2 presents the related work. Section 3 explains the proposed system in detail. Section 4 discusses the system implementation, evaluation and results. Finally, Section 5 presents the conclusion and possible future work.

2. Related work

Recent work attempts to improve physical activity either by providing an advice to increase physical activity level or increasing users' awareness of their current activity level. They rely mainly on mobile tools residing in smartphones and sensors in order to accomplish their tasks. In the following, the purpose of each system is presented in addition to its description, results, advantages and/or disadvantages.

The StepUp application [25] is an example of mobile applications that have been developed to encourage healthy lifestyles by improving physical activity levels. The purpose of this application is increasing physical activity levels by providing users a quantitative measure of their daily activities by counting the steps walked daily using the accelerometer sensor in the user's phone. This system was tested on 20 subjects. The resulted average accuracy was 93%. However, it does not provide the user with any advice on how to enhance their activity level, only the number of steps.

Flowie system is another example of utilizing sensors to improve physical activity levels [26]. It encourages seniors to increase their physical activity level by providing a virtual coach that motivates them to walk more. In a nutshell, the system works by reading data from a pedometer installed in the user's shoes and comparing them with pre-set goals. This data represents the senior's activity level is displayed as a visual flower. It also shows the weekly progress. A prototype of the proposed system has been implemented and tested on two participants for 11 days. As in StepUp, this system does not require any interaction from the user but it does not provide her with any advice to improve her activity level.

Motivate mobile application [27] is a mobile application that was developed to provide personalized guidance based on contextual data such as weather, user location, and agenda to enhance user physical activity by offering simple suggestions on a daily basis. A user study involving 25 users was conducted to evaluate the