A BIOFEEDBACK-BASED PHYSICAL ACTIVITY ADVISORY SYSTEM

by

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A Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the degree of
Master in Electrical and Computer Engineering

Ottawa-Carleton Institute for Electrical and Computer Engineering
School of Electrical Engineering and Computer Science
Faculty of Engineering
University of Ottawa

Ottawa, Ontario, Canada, 2014

Abstract

Physical inactivity, a phenomenon on the rise in numerous countries, has gained global attention because of its negative effects on humans' physical wellness. It represents a stumbling block in the way of living a healthy lifestyle. Recent statistics of World Health Organization (WHO) ranked physical inactivity as the fourth leading risk factors for adults' mortality all over the world [1]. Also, physical inactivity is considered as one of the most prominent contributing factors in several severe diseases such as breast and colon cancer, diabetes and many heart- related diseases [1]. Therefore, improving daily physical activity levels is an urgent societal goal in order to tackle the physical inactivity problem. Achieving such challenging goal requires addressing the factors that affect adults' physical activity. In fact, there are many factors that lead to physical inactivity such as the busy lifestyle, lack of awareness regarding required physical activity levels and other environmental factors. Physical activity advisory systems can be seen as a promising solution for the inactivity problem. In order to enhance their effectiveness, these systems must take into account most of the factors previously mentioned. In this thesis, we aim to provide a method to promote the increase of daily physical activity levels by leveraging biofeedback and context awareness features. In order to achieve this purpose, we design and develop an algorithm that provides a user with personalized physical activity advice. This advice increases the user's awareness through the use of calories expenditure. To add a context awareness component to our algorithm, we propose an extension of the Ubiquitous Biofeedback (UB) Model [2]. We believe that combining the biofeedback feature with context awareness component would make the system sensitive to the user's status and thus increase the chances of her or him following it. This advice represents the daily-recommended amount of physical activity for maintaining healthy lifestyle according to [3, 4]and other international organizations' recommendations. In order to prove the concept of the proposed algorithm and extended UB Model, we design and develop a system called "CAB". It is a context aware biofeedback system that tracks user's physical movement and estimates the amount of calories burnt to provide the user with a personalized physical activity advice that considers user's current status, preferences and surrounding environmental context. The system utilizes a biofeedback sensor and a smart phone in order to provide the personalized advice that is

delivered to the user in a form of multiple-mode feedback/notification (text, audio and haptic). In this thesis, we provide detailed information about the design requirements, the design model, the proposed system and its related hardware components and software modules. The qualitative and quantitative evaluation of the developed system CAB shows a positive impact on the experiment sample group by motivating the participants to reach or exceed the recommended number of calories to be burned daily for most of the evaluation days.

Acknowledgements

This thesis would not have been possible without Allah (swt). First and foremost, I would like to thank Him for giving me the health, strength, and patience to persevere during my studies.

Also, it is a pleasure to thank those who have made this thesis possible...

First, special thanks goes to my beloved family: My beloved father Faiz, who passed away at the beginning of my Masters journey with a hope to see me as a professor, my beloved mother Aishah, my beloved husband Omar, my little sweethearts (Abdulrahman and Dana), my beloved brothers and sisters especially Yaser, my beloved father in-law and mother in-law, and all of my friends and people who have positive influence in my life especially Dr. Elham Hassanain, may Allah protect and bless all of them. I would like to express my sincere gratitude to them for their faith in me, their inspiration, and for understanding and supporting me throughout my graduate studies. They have provided me with so many things over the past years and continue their support to allow me to be as ambitious as I wanted. They are always my source of strength, support and the reason I have made it so far in life.

Also, I would like to convey my sincere and deepest gratitude to my great supervisor Prof. Abdulmotaleb El Saddik for his help, advice, continued support, patience, encouragement and guidance from the earliest stages of this research. I am extremely grateful to have been supervised by such an excellent and knowledgeable professor.

I owe my sincere and deepest gratitude to Mohammed Al-Hamid, Mohamad Eid, Samah Aloufi, Vanessa Macisaac, Mohammed Huda, Hussein Al Osman, Basim Hafidh, Jolia Ricketti, Dan Martin and Ali Karime for their valuable assistance, comments, and support during the progress of this work.

I would also like to express my sincere gratitude to all of the Multimedia and Communications Research Laboratory (MCRLAB) colleagues for the good times we spent together in this friendly lab.

Finally, special thanks go to my sponsor: Umm Al-Qura University in my beloved and home city: Makkah Al-Mukarramah.

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AAM:	Activity Advisory Module
ACSM:	American College of Sports Medicine
ADA:	American Diabetes Association
AHA:	American Heart Association
API:	Application Programming Interface
BM:	Biofeedback Module
CAB	Context Aware Biofeedback
CDC:	Centers for Disease Control and Prevention
CVD:	Cardiovascular Disease
DSM:	Data Storage Module
ECM:	Environmental Context Module
GUI:	Graphical User Interface
IOM:	Institute of Medicine
Kcal:	Kilocalorie
KJ:	Kilojoule
LTPA:	Leisure Time Physical Activity
MET:	Metabolic Equivalent of Task
Min.:	Minutes
OPA:	Occupational Physical Activity
PA:	Physical Activity
PAA	Physical Activity Advisory Algorithm
RMR:	Resting Metabolic Rate
UB:	Ubiquitous Biofeedback
UIM:	User Interface Module
WHO:	World Health Organization
WMR:	Work Metabolic Rate

Chapter 1

Introduction

1.1 Background and Motivation

Wellness is one of the broadest concepts that is used consistently to characterize the quality of a human's life. Extensive research has been conducted to define wellness and specify its aspects and its role in human lives; in addition to determining the factors that have the most impact on wellness. Consequently, there have been many attempts to provide a definition of wellness, which has led to the appearance of several corresponding or related concepts such as wellbeing, life satisfaction, quality of life, human development, flourishing, and happiness [5]. Maintaining a healthy and balanced lifestyle is one of the main factors that affects and contributes positively to individual wellness. In order to understand this contribution, we must first realize the strength of the relationship between a healthy lifestyle and wellness. In addition, we must investigate the role of physical activity, which is essential in this relationship. For decades many researchers have attempted to define wellness and there have been several arguments over this concept. One of these attempts [5] defines wellness by considering "wellness dimensions". It is worth mentioning that the research behind this idea is specified based on a summary of previous research works dedicated to defining wellness. Researchers concluded that there are eleven fundamental dimensions that can be used to define wellness. These are physical wellness, psychological/emotional wellness, social wellness, intellectual wellness, spiritual wellness, occupational wellness, environmental wellness, economic wellness, cultural wellness, climate wellness and governance/social justice wellness. Figure 1.1 illustrates the dimensions of this wellness definition.

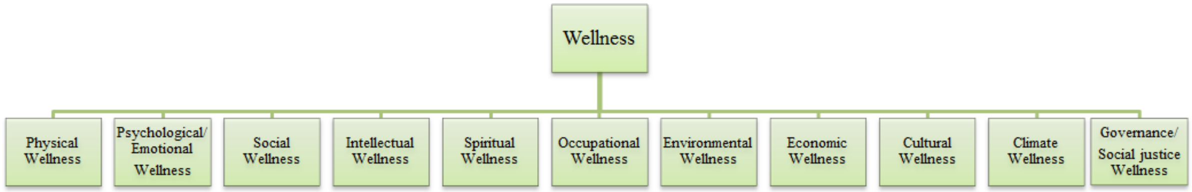


Figure 1.1 Dimensions of wellness definition [5].

Physical wellness is the dimension that we focus on in our research. Physical wellness is defined as the active and continued effort towards maintaining an optimum level of physical activity, focusing on diet and making healthy lifestyle choices including self-care [5]. From this definition, it is clear that physical wellness encompasses four main factors, which are illustrated in Figure 1.2: physical activity, nutrition, self-care, and healthy lifestyle actions. Healthy lifestyle actions could also appear under either the physical activity factor or the nutrition factor. Following a healthy diet and avoiding harmful habits such as smoking are examples of healthy lifestyle choices. Weight control intervention also has an essential role in the healthy lifestyle category. According to [6], there are several key elements that have an effective impact on weight control, which affects personal lifestyle positively. These elements are: diet, such as a low-calorie diet; physical activity, such as practicing a physical activity for short bouts daily; behavior such as daily monitoring of food intake; and psychosocial factors, such as social support. Therefore, based on the previous review of wellness, its dimensions, and its relationship with a healthy lifestyle, we find that physical activity plays a critical role in a healthy lifestyle. Daily diet and self-care that is represented by medical intervention is outside the scope of our search.

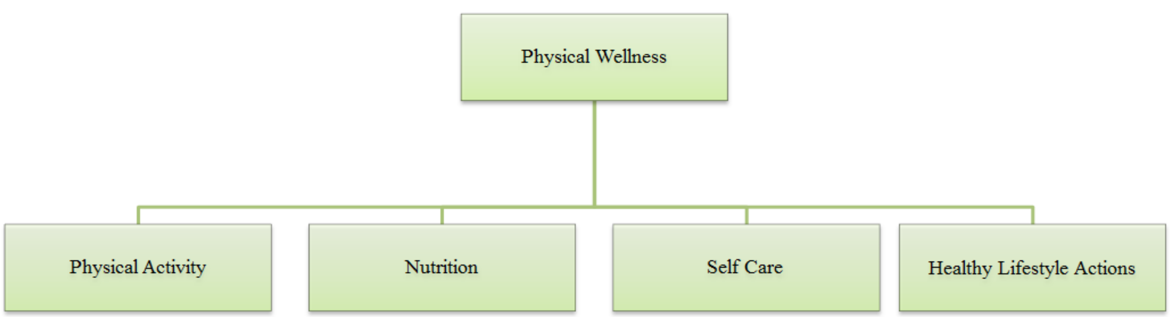


Figure 1.2 Physical wellness dimensions

Presently, physical inactivity has been ranked fourth in the list of leading risk factors for global mortality because it causes 6% of deaths globally [1]. According to WHO statistics, in 2008 about 31% of adults (28% of men and 34% of women) all over the world, aged 15 and over, were not sufficiently active [7]. Moreover, around 3.2 million deaths occurred annually due to physical inactivity [7]. Furthermore, statistics have stated that physical inactivity is evaluated as the main cause of many severe diseases. Approximately quarter of breast and colon cancers cases, 27% of diabetes, and 30% of ischemic heart disease burden cases are caused by physical inactivity [1]. Therefore, the increase in the levels of physical inactivity is noticeable worldwide, including high, middle, and low-income countries [7].

1.2 Research Problem

From the review of physical inactivity and the facts mentioned in the previous section, there is a need to promote physical wellness through adopting a healthy lifestyle thereby reducing the risk of non-communicable diseases. Hence, there is definitely an urgent need to motivate people to increase their physical activity level. But the question is: How can we motivate people to increase their physical activity level? The solution that we suggest in this work is intended to motivate people to perform a basic threshold of minimal daily physical activity that guarantees wellbeing, taking into account current conditions of users and their environmental context.

This minimum recommended threshold is a continuous or discrete 30 minutes of moderate intensity physical activity per day according to the American College of Sports Medicine (ACSM) [8], the American Diabetes Association (ADA) [9], the American Heart Association (AHA) [10], Centers for Disease Control and Prevention (CDC) [11] and WHO [12]. According to [13], moderate intensity physical activities are activities that have METs values ranges between 3-6 Metabolic Equivalents of Task (METs). Performance of moderate intensity physical activity for 30 min./day is recommended for reducing the risk of Cardiovascular Disease (CVD) in addition to other metabolic diseases [14]. However, in order to maintain a healthy lifestyle, the Institute of Medicine (IOM) recommends 60 min./day of moderate intensity physical activity[3, 6] . Also, research in [4] recommends 60 minutes of Leisure-Time Physical Activity (LTPA) per day at intensity of 3 METs for optimal health results. The CDC has proven that 3 10-minutes short bouts are as efficient as one 30-minute bout [11].

We consider mobile computing technology as an effective tool that can be used towards motivating a given user to perform some physical activities. In fact, mobile computing technology can provide a user context since it enables resource sharing and data transportation among computers or other smart devices such as smartphones [15]. Research in [16] Specifically, modern smartphone capabilities have opened many doors for new mobile applications because they are programmable mobile devices that make use of complete operating systems in a similar way to traditional computers [17]. These advancements have increased the usage of smartphones for many different purposes beyond being a communication device, and this has resulted in an increase in users becoming reliant on their smartphones, which transforms their usage habits [17]. A recent study shows that 35% of American adults own a smartphone, and a quarter of them do most of their online browsing using their smart phones [18]. The percentage increased by the year 2013 to be 56% [19].

Consequently, as long as smartphones provide more and more applications, the user-smartphone relationship will become stronger, and smartphones will become an integrated part of users' everyday lives [17]. Therefore, developing a mobile activity advisory application that aims to increase physical activity levels for users using smartphones is a promising solution to minimize physical inactivity. These activity advisory systems need to be sensitive to the current situations of users and their surrounding environments in order to provide suitable advice. To enable this, knowing the user's context is an essential factor. Fortunately, smartphones are currently equipped with features that facilitate acquiring context data. Smartphone applications are used as data collection platforms because of their programmable nature and the useful smart sensors built into the devices. This can turn them into inference tools to detect daily habits in a user's life [17].

However, the user's context data are not sufficient to provide personalized activity advice that aims to increase user's physical activity level. Tracking physiological changes inside a user's body is another essential factor that could be used to personalize the provided advice. Although this factor is crucial in a physical activity advisory system, it is not considered in most of existing systems. Biofeedback technology is an optimal technique to accomplish this task. This involves tracking physiological changes in a user's body and sending the data to the computer system in a synchronous manner. Biofeedback technology is defined as 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 about these attributes and facilitate the responding process to their changes [20]. It deploys various sensors, which represent information sources, to provide critical information about physical conditions of the human body during continuous tracking [21]. Modern smartphones are now equipped with smart sensors to detect directions and movements. These accelerometers and gyroscopes can be utilized efficiently to provide valuable data about a user's current movement and direction because accelerometers are one of the most efficient sensors that provide continuously vital data about individuals' physical activities [22].

1.3 Research Objective and Contributions

From all the previously mentioned facts, we have been strongly motivated to propose our solution to the global challenge of physical inactivity. Our solution is summarized in the following points that represent the thesis contributions:

- Design and development of a physical activity advisory algorithm: This algorithm employs the concept of calories burned through performing different physical activities to provide physical activity advice to the system's users while considering the environmental context. This advice represents the daily-recommended threshold for maintaining a healthy lifestyle, which is continuous or discrete 60 minutes of moderate intensity (3-6 METs) activity per day. In this way, our algorithm will help users to be aware of the amount of calories burned in their bodies that are resulted from performing different physical activities as a step towards being daily active for maintaining a healthy lifestyle.
- Extend the Ubiquitous Biofeedback (UB) Model [2] to add a context awareness component: This extension of the reference model can be utilized with physical

activity advisory systems to provide context-aware biofeedback advice in order to encourage the user to follow it as a step towards improving the physical activity level of individuals.

- Design and development of a system as a proof-of-concept for the proposed algorithm and the extended UB model: We developed a system called CAB, which stands for Context Aware Biofeedback, that uses the amount of calories burned to motivate the user to perform more physical activities.

Our work in this thesis differs from existing physical activity advisory systems in the sense that it combines the biofeedback technology with environmental context data to be utilized in physical activity advisory systems that can provide personalized and useful recommendations at the right time and at the proper location. In fact, our main objective from this work is to promote a healthy lifestyle by increasing physical activity levels through increasing awareness about the amount of calories burned in our bodies which results from performing different physical activities. Also, the developed system targets individuals who work in office environments, such as researchers and administration employees, to help them to be more active as a step towards improving physical activity level. As mentioned previously in Section 1.1, healthy lifestyle actions, which is the fourth factor of physical wellness could appear under either the physical activity factor or the nutrition factor. Our proposed system CAB, which is developed to prove the proposed algorithm and the extended UB model, fits under the physical activity factor as an example of healthy lifestyle actions that take the user context into consideration.

1.4 Author's Publications

1. Hawazin Badawi and Abdulmotaleb El Saddik, "Towards a Context-Aware Biofeedback Activity Recommendation Mobile Application for Healthy Lifestyle", *Procedia Computer Science 21* (2013): 382-389.
2. Amani Albraikan, Hawazin Badawi, Abdelwahab Hamam, Abdulmotaleb El Saddik, "Haptibasic: Learning basic concepts of a haptic technology through edutainment

games", in *Proceedings of the 2013 IEEE International Conference on Multimedia and Expo Workshops (ICMEW)*, San Jose, CA, United States of America, 2013: 1-4.

3. Hawazin Badawi, Mohamad Eid, Abdulmotaleb El Saddik “A Real-Time Biofeedback Health Advisory System for Children Care”, *in Proceedings of the 2012 IEEE International Conference on Multimedia and Expo Workshops (ICMEW)*, Melbourne, Australia, 2012: 429-434.
4. Hawazin Badawi, Mohamad Eid, and Abdulmotaleb El Saddik “Diet Advisory System for Children Using Biofeedback Sensor”, *in Proceedings of the 2012 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, Budapest, Hungary, 2012: 1-4.

1.5 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2 presents a literature review about the concepts related to physical activity and which biosensors are utilized in the field of physical activity monitoring. Also, it presents related works and shows how our work differs in a comparative manner.

Chapter 3 explains in detail the proposed algorithm, the proposed extension of UB model and system design. It starts by specifying the requirements for building a successful physical activity advisory system.

Chapter 4 presents the hardware devices and software modules used to implement the prototype of the proposed system. It also provides a descriptive example of the system implementation through the presentation of one of the participants’ experiences in a system evaluation.

Chapter 5 presents the evaluation of the proposed algorithm and the extended UB model through evaluation of the system that was implemented in Chapter 4 as a proof-of-concept for this algorithm and extended reference model. Also, it explains in detail the evaluation plan, the qualitative and quantitative evaluations, and depicts the results.

Finally, in chapter 6 we conclude the thesis by summarizing the results and showing the suggested future work.

Chapter 2

Literature Review and Related Work

This chapter first provides a review of the background literature related to the main concepts of physical activity and describes the different biosensors for monitoring and measuring such activities. Next, a survey of existing physical activity monitoring systems developed for improving users' physical activity levels is presented. These systems aim to either increase users' awareness about their activity level or to provide them with advice in order to increase their activity level towards the levels of a healthy lifestyle.

2.1 Literature Review

This section consists of two main parts. The fundamental concepts of physical activity are presented in Section 2.1.1. The next section gives a general overview of biosensors used to monitor and measure physical activity levels, including some commercially available sensors.

2.1.1 Basic Terminologies

One of the early contributions towards defining physical activities is the definition provided by [23], which defines "physical activity" as any physical movement that results from contraction of skeletal muscles and leads to an increase in energy expenditure. Many researchers have attempted to classify physical activities. One of these classifies physical activity into two main categories [24]: Occupational Physical Activity (OPA) and Leisure-Time Physical Activity (LTPA). OPA refers to those activities associated with one's daily job within the period of eight hours per day. LTPA refers to a broad range of activities that a person performs during free time according to personal needs and preferences. Also, there are two subcategories that come under LTPA: Aerobic Exercise and Resistance Exercise.

Regarding the measuring process of physical activities [23], it is an agreed upon standard to use the amount of energy burnt during an activity for this purpose, and it is measured in kilojoules (kJ). However, kJ is often replaced by measurements in kilocalories (kcal) even though kcal is a measure of heat, but it is the preferred measurement unit for measuring physical activities historically. In terms of numbers, 1 kcal equals to 4.184 kJ.

After deciding on a unit of measurement for physical activity, researchers defined reference values in order to facilitate the physical activity measuring process. Therefore, to measure the amount of energy required to perform a physical activity, we need to consider the Metabolic Equivalent of Task (MET) of the physical activity, which describes rate of energy expenditure [24]. For a specific activity, the metabolic rate is estimated by measuring oxygen uptake and carbon dioxide production where oxygen uptake is measured in kcal using a constant of 5 Kcal/L [24]. This is known as the Work Metabolic Rate (WMR), and it needs to be compared to the Resting Metabolic Rate (RMR) to get the MET. The oxygen uptake of 3.5 mL/kg/min used as an approximation of RMR and considered as 1 MET. In other words, the MET of a physical activity is defined as the ratio of the Work Metabolic Rate (WMR) to a standard Resting Metabolic Rate (RMR) [24] :

$$MET = \frac{WMR}{RMR} \qquad (1)$$

Another fundamental concept in the physical activity domain is a physical activity dose [24]. The physical activity dose needed to reach a specific goal is determined by four factors: activity intensity, activity frequency, activity duration, and activity type. Intensity describes the effort required to perform the activity and it varies according to the activity category (LTPA or OPA). This effort represents the WMR in the above formula. MET, which is explained above, is commonly used as an index for the intensity of physical activity [4]. In fact, physical activity intensity represents by one of three values: light (<3 METs), moderate (3-6 METs) or vigorous (>6 METs) according to [13]. Frequency denotes the number of activity sessions per day, week, or month, whereas duration is the number of minutes spent in an activity session. Type specifies whether it is leisure, aerobic, resistance or occupational physical activity.

Conveniently, there exist standard tables of MET values for different physical activities. Researchers in [4, 24] provide a wide range of physical activities, vary in their intensity, and confirm the MET values accordingly. Table 2.1 shows examples of some activities with MET values for each. It is worth mentioning that the physical activity can have different MET values with respect to the intensity. The walking activity as presented in Table 2.1 is an instance of such a case, where depending on the intensity; it is taking different MET 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
Shoveling snow by hand	6.0
Climbing the stairs	8.0
Running	8.0

Table 2.1 Examples of physical activities with corresponding MET values

2.1.2 Using biofeedback sensors to monitor and measure physical activity

Biofeedback technology has been used in many medical and non-medical applications, serving many purposes due to its unique capabilities [21]. This technology represents an essential source of vital information about human body conditions in a real-time manner, such as body posture and heart rate frequency [21]. This tracking and measuring of physical activities can be achieved by direct measurement through the use of wearable monitors and various types of sensors. Pedometers, accelerometers, and heart-rate monitors are instances of these sensors. A pedometer's main function is counting steps, and it is worn on the waist.

Their main features are unobtrusiveness and low cost, however, the reliability and the validity of the collected data clearly differs from model to model [25]. Recently, several studies that focus on increasing physical activity have used validated pedometers as a major source of data (number of steps per day). Pedometers are useful when we need to assess activities involving a group of individuals performing at the same time or for tracking daylong activities, but they are known to be limited by memory storage for some models [25]. Heart-rate monitors track physical activities through tracking heartbeats by measuring the heart's electrical activity via a device attached directly to the user's chest. Most of these monitors come with a peripheral device such as a watch to read the output data. Accelerometers are another example of popular sensors in the physical activity field. They are used for monitoring and recognizing body postures, such as standing, walking, and sitting [26]. Currently, there are several activity-monitoring products available commercially that utilize accelerometers to track a user's physical activity. Nike Fuel Band [27] and Fitbit Ultra [28] are examples of such products. Table 2.2 shows more examples of these products.

Product Name	**Product Picture**
Nike+ [29]	
MOTOACTV™ [31]	
fitbit zip [32]	
fitbit one [33]	
UP by JAWBONE [34]	
Gruve [30]	
PHILIPS directlife [36]	
NIKE+ FUELBAND [27]	
larklife [37]	
Misfit Shine [35]	

Table 2.2 Examples of physical activity trackers (accelerometers) available commercially

2.2 Related Work

Based on our previous review of wellness, its dimension and its relationship to a healthy lifestyle, we can conclude that healthy lifestyle promotion can be achieved through three main paths: physical activity, diet, and self-care or medical intervention, which is outside the scope of our research. Thus, the proposed system in Chapter 3 attempts to promote a healthy lifestyle through the first path, “physical activity”, in the form of an activity advisory system based on biosensor data and user context. In this section, we present a group of recent physical activity monitoring systems. These systems are used to improve physical activity levels and promote healthy lifestyles by either increasing users’ awareness of their activity level or by providing them with advice to increase their physical activity level. Researchers used various tools in these systems, such as smartphones and sensors. An overview of each system is provided to show its purpose, description, results of the system, and main advantage and/or disadvantage of the system.

Many applications have been implemented to promote healthy lifestyles by enhancing physical activity levels. To begin with, work in [38] is an example of such a developed application. The StepUp application was developed as a smartphone application to promote healthy lifestyles for people living in the Gulf area, which suffers from one of the highest rates of diabetes and obesity in the world, according to [38], because of a dominant sedentary lifestyle and easy access to food that is rich in fat and poor in nutritional content. This application aims to increase physical activity levels by giving users a quantitative measure of their daily activities. It works by counting the steps walked daily using the accelerometer sensor in the user’s phone, thereby giving users a simple overview of their daily activities. The main purpose of this system is to increase the user’s awareness and motivate them to perform more activities in order to increase the number of steps. An experiment on 20 subjects was conducted to prove the accuracy of the proposed step detection algorithm. It resulted in 93% as an average accuracy. The main advantage of this system is that it gives feedback to the user about his/her activity level without any required interaction with the system from user’s side. However, it does not provide the user with any advice on how to increase their activity level, only the number of steps.

Another example of utilizing sensors to improve physical activity levels is the research work in [39]. It aims to encourage seniors to increase their physical activity level by providing a virtual coach to motivate the elderly people to walk more by way of a visual interface. The proposed system, called Flowie, has been designed and developed based on discussion results from a panel of seniors who are also involved intensively in the design process in order to deliver a system that meets users' needs precisely. Briefly, the system reads data from a pedometer installed in the user's shoes. This data represents the user's activity level, and it gets compared with pre-set goals. Then, the graphical user interface (GUI) displays the user's activity level as a representative visual flower. It includes a tracking feature for the current number of steps compared to the target number, and the weekly progress gives meaningful feedback to the user in a simple way. A prototype of the proposed system has been implemented and tested on two participants for 11 days. They responded positively about the system and stated that the system has motivated them to exercise more and more in order to reach their daily goal. The main advantage of this system is similar to StepUp system mentioned previously since it gives a feedback to the person about his/her activity level without any required interaction with the system from user's side. It simply receives data from the pedometer and uses an attractive GUI. However, it does not provide the elder person with any advice to increase their activity level, only the number of steps with a date and time.

Context-aware technology is another technology that has been deployed as a means to encourage healthy lifestyle. An example of using context-aware data in this manner is shown in research work in [40-42]. In this work, a mobile application called Motivate is developed to provide personalized guidance based on contextual data such as weather, user location, and agenda. Researchers aimed to improve user behavior with regards to physical activity by offering simple suggestions on daily basis. They conducted a user study on 25 Android phone users in order to evaluate the implemented application. The Motivate system sent 3556 messages, and 47.8% of the messages received positive responses from participants. Thus, the system evaluation shows the potential of Motivate to improve the physical activity level of its users. The main advantage of this system is that it provides user with personalized suggestions or recommendations according to his/her agenda and environmental context/location. However, these recommendations only satisfied half of the evaluation group because the agenda consideration was not accurate enough. 57.1% of all the messages were considered to be sent on time, but 25.6% of them were considered to be too late and 17.3% of them were considered to be too early. Moreover, the system needs manual interactions from the user in that they needed to set a daily agenda to help the system to perform its task. This adds more responsibilities for the user, which in turn may drive the user to avoid using the system. Furthermore, even with agenda setting the system evaluation shows that half of the messages were refused by receiving negative responses from the user due to inappropriate timing or bad weather.

Finally, research in [43] is another example of using smartphones as a means to promote physical activity. In this work, the researchers developed an ambient information system to help seniors to be more active. The system is called CAMMInA, which stands for (Calm Application for Motivating elders to Move by Interacting with their Age group), and it provides visual and auditory notifications to remind a user to go for a walk. Also, it represents user performance graphically by using coins of different values as a reward to motivate seniors to achieve their goals. This system starts by notifying a user to go for a walk and displays the recommended time span, such as 30 minutes, in addition to displaying a copper coin. Then, it sets another goal for the user to walk half of this time period in order to get a silver coin. If the user reaches the first goal they will get a gold coin and social interaction with the group, which is worth a diamond. User performance is displayed in the form of a three-week calendar: the last week, the current week, and the coming week. The design and implementation have been approved based on a user centric approach, and four different persuasion strategies, namely abstraction; historical information and reflection; triggers for exercising; and positive and playful reinforcement. A usability study to evaluate the system has been conducted on 15 subjects ranging in age from 63 to 86 years old. For one day, subjects exercised at a Senior Center of the Mexican Institute of Social Security, attending two different sessions: an introductory session to explain the system's function and a session where they used the system on their own. The usability study gave positive feedback to the researchers about the system, which in turn enabled them to improve the design and to understand the effect of the four persuasion strategies on the system's performance. In fact, it motivated half of the elders to be more active through the interactive GUI using metaphorical coins as rewards. The coins encouraged them to follow the walking advice and they liked the audible notifications. However, the other half of the elders who tried the system stated that system reward mechanism based on exercise time is not interesting enough to encourage them to follow the exercise advice. They suggested that personalized feedback, such as recording the number of calories burned from performing the exercise, would show how active the user was and motivate them more. They also recommended having different physical activities instead of walking only.

2.3 Comparison and Summary

We developed our system “CAB” in a way that overcomes the disadvantages of the previously mentioned systems. These disadvantages are summarized in the points below:

- With regards to the existing systems that provide biosensor data as feedback to show how active the person is, such as the number of steps taken, the systems did not provide useful advice or recommendations for the users in order to improve their physical activity level. Systems like StepUp [38] and Flowei [39] benefit minimally from the biosensor values and limit their roles as a tool that notifies users about their current status without any tangible action to improve these values.
- Regarding the systems that provide physical activity advice or recommendations to the users in order to increase their activity level, they provide general and not personalized advice. This may not be suitable for a user’s physical conditions, commitments, or preferences such as CAMMInA [43] Motivate [40, 41]. Also, they did not provide feedback that reflects user physical activity level, and they require a manual interaction with the system in order to perform its task [40, 41] or a time-restricted response [43]. These interaction approaches may drive the user to ignore the system suggestions even if they are attractive visual or audible advice, or in the worst case they could avoid using the system at all since it adds more daily responsibilities on the users. Thus, providing general advice in attractive interfaces is not enough to encourage users to be more active. There is an urgent need for personalized advice that considers user context and preferences, and provides biological values that represent real activity levels.

- Also, it is important to mention that in the most related work to our system, Motivate [40], they stated, “Among all kinds of advice we noticed that the easy-to-do activities such as ‘coffee break’ or ‘taking the stairs’ were sent to users more often and those messages received more positive responses as well. Although these small activities do not increase the physical activity to a level of calorie burning, they do help users to adopt a healthy lifestyle by changing habits.” In fact, they reached this conclusion because they consider user’s context only. However, in our system, when we considered the biofeedback feature in addition to the user’s context, we found that performing these easy-to-do activities causes calories burning, enhances and helps to improve user’s physical activity level, as will be seen in Chapter 5.

In brief, we designed and developed a system to accommodate the previous systems’ advantages and solve most of their disadvantages, in addition to proving that the biofeedback feature is a successful factor in such systems. Our system “CAB” is designed to provide personalized advice to the user based on his/her current energy expenditure, and this advice will be sent in advance in order to facilitate having the users follow the provided advice. Personalization occurs in taking into account biosensor data, which are collected by an accelerometer as a source of automatic input to the system. We also take environmental context into account as a form of context-awareness in the developed system. Thus, our system “CAB” aims to encourage users by sending an appropriate suggestion at a suitable time while mentioning the number of calories burned compared to the target number of calories that must be burned daily for living in a healthy lifestyle. It notifies the user in three different forms: visual, audible and haptic notifications. Chapter 3 and Chapter 4 will present detailed explanations for our proposed system.

Table 2.3 presents a summary of previously mentioned systems compared to our system “CAB”. For each system, the table shows the system’s Target, which is either adults in general or elders specifically. Next, the Source of Input in the second column shows the source of each system’s data, which is either a sensor attached to the subject’s body that provides the system with data automatically or a manual interaction, which means that a user needs to enter the data into the system in order to perform its function. The third column is Type of Output. It can be either personalized output, which means the system provides advice personalized to the user context or it provides a general output, which reflects the user's current status or performance. Feedback Type is in the fourth column, which shows the way the output of the system is displayed to the user. This can be either visual output in the form of a textual interface/GUI, an audio signal such as voice messages, or haptic (sensible) output such as vibrations.

System Name	Target		Source of Input		Type of Output		Feedback Type		
	Adult	**Elder**	**Sensors**	**Manual**	**Personalized**	**General**	**Visual**	**Audible**	**Haptic**
StepUp: A Step Counter Mobile Application to Promote Healthy Lifestyle	✓		✓			✓	✓		
Flowie: A Persuasive Virtual Coach to Motivate Elderly Individuals to Walk		✓	✓			✓	✓		
Motivate: Context Aware Mobile Application for Activity Recommendation	✓			✓	✓		✓		
Persuasive Strategies for Motivating Elders to Exercise		✓		✓		✓	✓	✓	
CAB: Our proposed System	✓		✓		✓		✓	✓	✓

Table 2.3 A summary of the related work and how it compares to our proposed system CAB.

Chapter 3

Proposed System

In this chapter, we present the requirements specification phase needed to facilitate the design of our proposed system and prove the concept of the proposed algorithm and the extended UB model. We also discuss the architectural design for the proposed system and its hardware and software components. We started by outlining the main lessons learned from the related work mentioned in Chapter 2. This represented a roadmap for us to determine system requirements. Then we conducted a questionnaire – see Appendix A- that aimed to survey the physical activity level of participants and to determine the most important contexts that need to be taken into account in the design phase. This also helped to evaluate an acceptance level for utilizing biofeedback technology. In addition, we study the preferred feedback mode through interview. Section 3.1 presents the requirements specification phase. Section 3.2 explains the UB model that we refer to when we design our proposed system. Section 3.3 presents the proposed extension of the UB model. Section 3.4 explains in details the proposed algorithm. System overview is presented in Section 3.5. Section 3.6 presents system architecture and a discussion of the system's software and hardware components is presented in Section 3.7. Section 3.8 displays use case diagrams for the proposed system, and we conclude this chapter with a system scenario represented as a sequence diagram in Section 3.9.

3.1 System Requirements

This section outlines the set of requirements for the proposed system based on the facts and characteristics discussed in Section 1.2 and on our objectives stated in Section 1.3 in addition to the basic facts mentioned in Section 2.1.

3.1.1 Design Requirements

We conducted an extensive research in order to determine the most significant features that we must include in our proposed system to solve the problems in the existing systems and fulfill our requirements. We consider the summary of the related works that is mentioned in Table 3 in Chapter 2 in addition to explore the design requirements for technologies used to encourage physical activity [44].

Thus, we concluded several main points that represent guidelines for specifying our system requirements. In order to develop a successful context-aware biofeedback physical activity advisory system that provides useful advice, the system needs to be:

- A Biofeedback System: Although the consideration of real-time physiological conditions of an individual's body, such as calories burned, is crucial in such a system, it is not considered in existing systems. A successful physical activity advisory system will need to consider biofeedback features according to the UB reference model presented by [2] in order to track physiological changes in the individual's body and send them to the system in a synchronous manner. The system can then process them and provide the advice containing these biological values to the users to inform them about their current status and try to encourage them to follow the advice. Sensory technology must be utilized in the biofeedback system to collect the bio-data continuously and update the system with this data. This facilitates system usage and minimizes the user's responsibility while using the system. Developing a biofeedback system meets one of the key design requirements of technologies that encourage physical activities [44], which states that the technology must provide personal awareness of activity level. This personal awareness incorporates three dimensions: activity level performance, current status and history of past behavior, which are must covered by the proposed system.
- An Environmental Context-Aware System: We noticed that the existing systems that provide physical activity advice suffer from the drawback of not being able to provide their advice in a proper time or place, which may result in the user ignoring or even refusing the provided recommendations. Thus, successful physical activity advisory systems have to consider the user's surroundings in

order to provide the advice at the proper time and the suitable place to increase its chances of acceptance by the user. Developing an environmental context-aware system meets another key design requirement of technologies that encourage physical activities [44], which states that the technology must consider the practical constraints of users' lifestyles.

- A Mobile System: A successful system needs to be a mobile system, which means it must work on multiple platforms to guarantee convenient usage (platform independent). This facilitates system usage and minimizes the user's responsibility while using the system.
- Able to Provide a Standard Advice: The advice provided by the system must follow the international standard for daily-recommended physical activity. The minimum recommended threshold, mentioned in Section 1.2, is a daily physical activity dose, a terminology mentioned in Section 2.1.1, performed for at least 30 minutes and with moderate intensity (3-6 METs) according to AHA [10], CDC [11], and WHO [12] to reduce the risk of CVDs and other related diseases [14]. In order to maintain a healthy lifestyle, a daily physical activity dose performed for 60 minutes and with moderate intensity (3-6 METs) is recommended according to IOM [3, 6] and [4].
- Able to Provide Multimedia Output: Most of the physical activity advisory systems have a single mode of feedback, typically visual feedback either as a textual feedback or a GUI. According to our study (Section 3.1.3) that aims to specify the preferred feedback mode, we found that multiple modes of feedback/notification are preferred by most of the participants (67%).

In light of these factors, we decided to conduct a questionnaire in order to survey the physical activity level status in a random sampling of adults. Also, we conducted an interview to specify the preferred feedback mode.

3.1.2 Survey the Physical Activity Level of Adults

According to the previously mentioned requirements, we decided to design a survey that aims to:

- Determine the importance of the proposed system by assessing users' current physical activity levels
- Determine environmental contexts that have the most impact on personal physical activity levels
- Determine the acceptance level for utilizing biofeedback technology in the proposed system

We conducted the questionnaire with a random sample of 28 individuals aged between 20 and 59 years old, where most of them were age 30.We used Google Form (see Appendix A) to create and distribute the questionnaire and collect responses. First we asked them about the daily period that they spend exercising in order to evaluate the overall physical activity levels for this random sample. As a result, 46% of participants reported they typically exercise for less than 15 minutes daily, whereas 25% said they do not exercise on a daily basis. Additionally, daily exercise for a period between 15 to 30 minutes or for a period between 30 to 60 minutes per day was applicable to 14% of the respondents for both categories. As we mentioned in Section 1.2, the minimum recommended threshold is 30 minutes per day of moderate physical activity (3-6 METs). In our case, 75% answered "No" whereas 25% answered "Yes" when we asked them explicitly whether they met this recommended daily threshold. 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. Consequently, this percentage shows the possible efficiency of the proposed system to solve the problem of physical inactivity.

Regarding context awareness, we asked the participants about which contexts or conditions have the most negative impact on their physical activity level. As we mentioned in Section 1.3, our system targets individuals who work in office environments, such as researchers, programmers, and administrative staff. We suggested seven different contexts that may have a negative impact on their physical activity level in order to determine the most important contexts that we need to consider in the system design. These contexts are: weather conditions, location, work environment, work commitments such as appointments and deadlines (calendar), the person's mood, the person's weight, and personal health conditions. Also, we gave options to select all of them or none of them with specifying the non-mentioned context. Weather conditions ranked as the most significant context that affected physical activity, with a percentage of 23%. Other contexts ranked as follows: calendar (18%), person's mood (18%), work environment (14%), location (9%), person weight (6%), and health conditions (5%). These percentages facilitated the task of picking the proper context to focus on when designing a useful context-awareness physical activity advisory system.

Regarding the deployment of the biofeedback sensors in the proposed system, we asked participants if they would agree to attach biofeedback sensors to their bodies in order to track energy expenditure, and their answers were: Yes (68%), No (14%), and Not Applicable (NA) (18%). This high percentage of acceptance motivated us to design the system by utilizing a biofeedback sensor to provide personalized recommendations.

From the survey results, we were able to determine the design of the proposed system in addition to its structural components, which will be presented in the next sections.

3.1.3 Study the Preferred Feedback Mode through Interviews

In order to decide on the system's feedback/notification mode (whether it should be single or multiple modes), we interviewed 9 subjects who represent a sample of the system's targeted category (researchers and programmers working at a university lab). We started the interview by giving a brief description of the proposed system. Then, we asked them four questions in order to determine the preferred feedback/notification mode:

Q1. In such a system, would you prefer a single mode of feedback/notification (visual, audible or haptic feedback) or multiple-modes of feedback/notification? Also, we presented a description of each feedback/notification method by giving the following examples:

- Visual feedback/notification: receiving an SMS on your phone or noticing a GUI or a pop-up message appearing on your computer screen
- Audible feedback/notification: hearing a voice message from your phone or a computer notification

- Haptic feedback/notification: feeling a cellphone vibration or your chair vibrating to notify you

Q2. Please give a score for each mode out of 10 and specify why you provide this score?

Q3. From your point of view, is visual feedback/notification enough?

Q4. Will audible and haptic feedback/notification improve your response or help you to respond faster to the recommendation?

A summary of the subjects' answers is shown in Table 3.1. In this table, S denotes single feedback/notification, M denotes multiple feedbacks/notifications, Y denotes "Yes" and N denotes "No". With regards to subjects' preferences, 6 subjects out of 9 (67%) preferred multiple-modes of feedback while the rest (33%) preferred a single-mode. We noticed that 6 out of 9 subjects gave a high score (8 and up) to haptic feedback/notification, suggesting that working in a sitting position requires a strong feedback to be noticed. The visual feedback ranked second with 3 subjects giving it a high score (8 and up). The audible feedback/notification had 2 subjects out of 9 give it a high score (8 and up). Also, 6 subjects agreed that visual notification/feedback would not be enough for many reasons, such as "I check my phone less frequently", "I will read the recommendation and ignore it if I am busy or forget about it". The main reason behind the positive response to visual feedback/notification alone being enough is repetitive checking of phones or emails, although subject 2 agrees that audible and haptic feedback will improve and enhance the response to the recommendations. Briefly, 67% of subjects agree that audible and haptic feedback will improve or help response times to the recommendations.

Subject	Q1		Q2			Q3		Q4	
	S	M	Visual	Audible	Haptic	Y	N	Y	N
Subj1		✓	7	2	10		✓	✓	
Subj2	✓		6	9	10	✓		✓	
Subj3	✓		9	4	3	✓			✓
Subj4		✓	3	7	9		✓	✓	
Subj5		✓	4	4	8		✓	✓	
Subj6		✓	6	9	3		✓	✓	
Subj7	✓		10	1	5	✓			✓
Subj8		✓	7	4	10		✓	✓	
Subj9		✓	9	5	10		✓	✓	

Table 3.1 Interview Results of Preferred Feedback Mode

3.2 U-Biofeedback Reference Model

Our proposed system is designed based on the U-biofeedback reference model for ubiquitous biofeedback systems [2] after we extend it in order to add a context awareness component. Research efforts into the Ubiquitous Biofeedback reference model aspires towards a vision of ubiquitous applications and their related standards are considered pioneer work in this field. In general, the biofeedback field and its related applications classifies into two different forms: Clinical Biofeedback and Ubiquitous Biofeedback (UB). UB reference model was introduced for u-biofeedback applications, which are not bound by specific time or sittings unlike clinical biofeedback applications. It has been built based on the concept of the mind-body loop, also known as the Biofeedback Loop in which data captured from the human body are processed into meaningful information perceivable through any of the human senses [2]. Briefly, this loop starts by attaching one or many biofeedback sensors to the human body to read the body's signals. Then the collected data are converted from analog to digital data in order to prepare them for interpretation. The output of this interpretation stage is an electrical signal, which is sent back as signal to be perceived by any of the human senses. Then, human brain responds to this signal and acts by changing the mind's state, which in turn causes a change in the human physiological state, and the cycle starts again. U-biofeedback reference model sets the standards for the u-biofeedback applications and states their main components. It describes any u-biofeedback system by dividing its processes into two main components: awareness process and assistive process. Awareness process starts by connecting a biosensor to the human body to track and collect data about physiological parameters. The captured data are passing through the signal processor and then the signal analyser. The processed results are conclusions that are sent back to the human mind through a feedback interface, which in turn stimulates the human body response. At this stage the Awareness Process ends where it began: at the human body. The u-biofeedback application at the respond point differs in sense that it advises the user to adjust his/her current status physiologically or psychologically unlike the simple biofeedback application, which just informs the user about his/her current status. This advice represents the second component of u-biofeedback system, which is assistive process. All collected data and resulting information can be stored in a data repository for short or long term analysis and for reference. Moreover, the u-biofeedback model suggests that these captured data could be communicated to remote systems for a wider analysis. Figure 3.1 depicts this model [2].

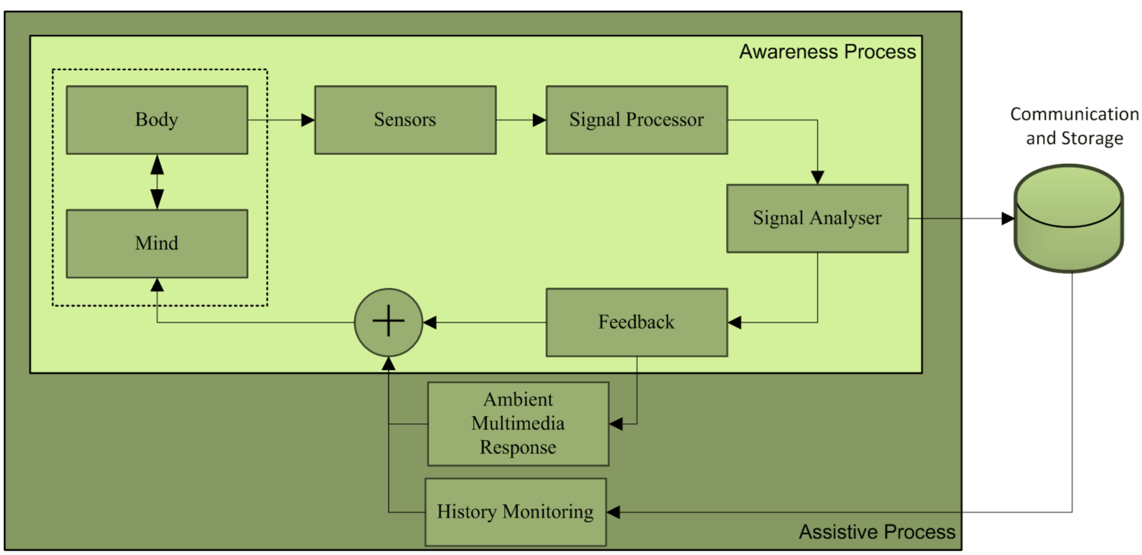


Figure 3.1 U-Biofeedback Framework [2]

3.3 Context-Aware U-Biofeedback Reference Model

In this thesis, we propose an extension for U-biofeedback reference model [2] by adding a context aware component in order to develop context-aware biofeedback physical activity

(PA) advisory systems. Figure 3.2 depicts this extension of UB reference model. With this extension, we suggest that the reference model consists of three main components: the Biofeedback Component which is Biofeedback Loop with its two processes, the Context-Aware Component, and the Communication and Storage Component. The Biofeedback Loop Component contains the core algorithm for the proposed PA advisory system, which is called PAA. PAA stands for Physical Activity Advisory algorithm. This algorithm, which is explained in the next section, is the main contribution of this thesis and designed to receive the biosensor data wirelessly and process them with other data in order to inform the user about this bio-data (awareness process) combined with an advice suitable for the current context (assistive process) through a computing device. Specifically, this algorithm fits in Ambient Multimedia Response part in the Assistive Process sub-component of Biofeedback Loop in UB model. In order to provide the advice at the proper time and place, Context-Aware Component sends environmental context data to the Ambient Multimedia Response part. The Communication and Storage Component is used for storing and retrieving the user's information and a predefined activity set.

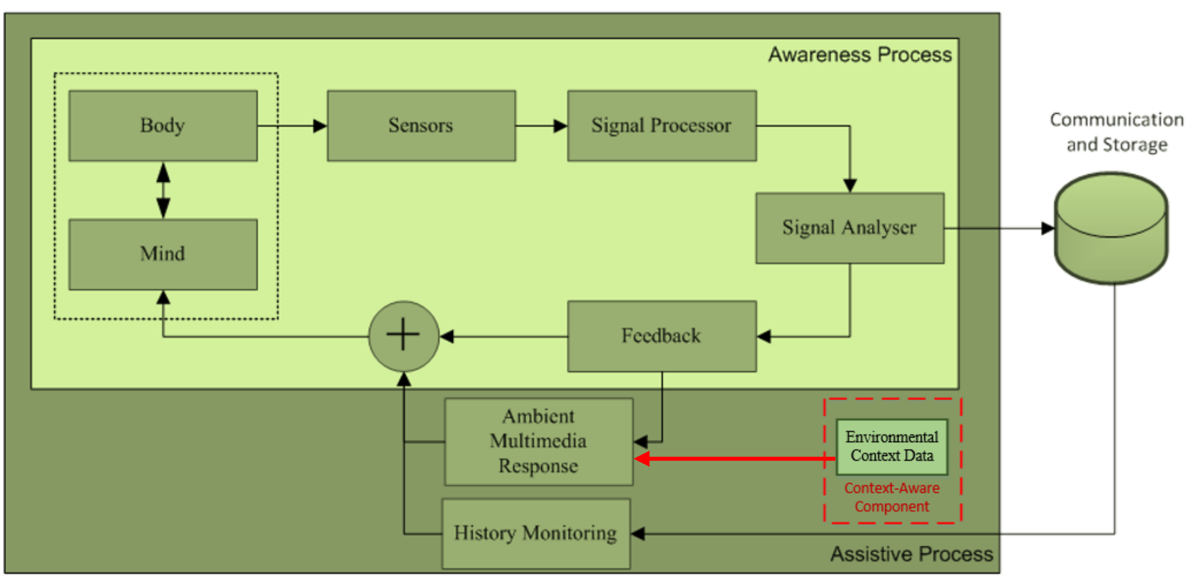


Figure 3.2 The proposed extension on UB Model: Context-Aware UB Model

3.4 Physical Activity Advisory Algorithm (PAA)

The proposed Physical Activity Advisory algorithm (PAA) retrieves data from the data storage component and the environmental context component shown in the previous section. It then provides contextual activity advice based on a user's energy expenditure, context, and preferences.

Estimating user's energy expenditure in PAA is accomplished by using calorie estimation formula in [4, 26]. This formula calculates energy expenditure according to the MET value for the physical activity that the user performs, user's weight in Kg and activity period in hours as follow:

$$\text{Energy (kcal)} = c \times \text{METs} \times \text{Weight (kg)} \times \text{Physical Activity Time (h)} \qquad (2)$$

The constant c represent a value = 1.05 which is a multiplication factor used in METs calculations based on the facts that the energy expenditure resulting from consuming 1.0 liter of oxygen is 5.0 kcal [4, 24].
As mentioned in Section 1.2, the minimum recommended threshold is a continuous or discrete 30 minutes of moderate intensity physical activity per day to reduce the risk of CVD and other metabolic diseases. Also, CDC has proven that three 10-minute short bouts are as efficient as one 30 minutes bout. In our work, we considered the recommended amount for maintain healthy lifestyle according to [3, 4], which is 60 min/day of moderate intensity PA. Regarding the METs, which is defined as the total energy expenditure of the physical activity according to [24, 45], we will consider moderate intensity physical activities which are associated with METs values between 3 METs and 6 METs according to [13].

In order to provide a useful advice, the proposed algorithm needs four main categories of data: personal data, context data, activity set data and biosensor data. Personal data includes user's personal data, user's favorite locations (favorite walking area, park, shopping mall, gym …etc.), and favorite activities (walking, biking, running ...etc.). Context data includes user's current location, weather and calendar. User's current location is used to guarantee providing the advice in the suitable location in addition to get correct weather data. Weather data is used to decide which type of physical activity should the advice provides (indoor/outdoor) activities according to current weather conditions. Calendar is used to guarantee providing the advice in the suitable time. Activity set data includes a predefined set of moderate intensity physical activities mapped to their METs values. Biosensor data is used in PAA algorithm to calculate calories expenditure.

PAA starts its work by retrieving user's personal data and calculating the optimal amount of calories the user needs to burn daily through performing physical activities using formula (2). In this calculation of optimal calories expenditure, Physical Activity Time in formula (2) will be given a value of 1 to represent 60 minutes per day and METs will be given a value of 3, which is the minimum of METs values for moderate intensity physical activities.

Then, PAA captures biosensor data to estimate user's current calories expenditure. After that, PAA compares current calories expenditure with the optimal calories expenditure. If the amount of calories burned is less than the optimal amount, PAA checks user's calendar to determine if he/she has an upcoming appointment or not. If the user has an appointment, the distance from user's current location to the appointment's location will be calculated in order to determine if the appointment's location is in user's surrounding area so he/she can use one of the proper activities in the Activity Set to reach the location. If this is the case, PAA reads weather data to check if it is suitable for outside activity. If weather is suitable, PPA estimates the required time to reach appointment location using each proper activity in the activity set such as walking and biking, in addition to estimate the number of calories that will burn in the estimated time for each activity. Consequently, PAA generates and displays a personalized PA advice with multiple activity choices to the user taking into account user's preferences by giving highest priority to user's favorite activities. Thus, the algorithm can generate a physical activity advice that considers appointment's location. However, if the user has an appointment and the weather is not suitable or if he/she has no appointment, PAA considers a short bout (10 minutes) as assigned time for the next advice. So, it estimates the number of calories that will burn in this short bout (10 minutes) for each activity in the activity set taking into account weather conditions, user's favorite locations and activities. Consequently, PAA generates and displays a personalized PA advice with multiple activity choices to the user assigning the highest priority for user's favorite activities.

Therefore, PAA proceeds in a repetitive process, which is checking the amount of burned calories, comparing it to the optimal calories expenditure and providing advices as long as the current amount is less than optimal amount of burned calories. This checking process continues until the end of the day when PAA generates a report advice for the user, which reflects his/her performance in this day through displaying the amount of burned calories compared to the optimal amount. In case the user reaches to the point where the amount of burned calories equals to or exceeds the optimal calories expenditure during the day, PAA notifies the user through an encouraging notification in the report advice and stores the day data for future references. Thus, the algorithm function terminates by saving the day data for future references. Figure 3.3 shows the flowchart of this algorithm and its pseudo-code is described in the following:

Physical Activity Advisory Algorithm

Get User's Weight
Get User's Current Location
Get Next Entry in User's Calendar
Get Current Weather
Get Pre-defined Activity Set as a Reference
Calculate User's Optimal Daily Calories Expenditure Using Equation (2)
REPEAT
Get Biosensor Data
Estimate User's Current Calories Expenditure Using Equation (2)
Compare User's Current Calories Expenditure with User's Optimal Daily Calories Expenditure
    IF User's Current Calories Expenditure < User's Optimal Daily Calories Expenditure
        IF User has an appointment
            Estimate distance from User's Current Location to the Appointment Location
            IF Current Weather is suitable
                FOR each activity in a Pre-defined Activity Set
                    Estimate Time from User's Current Location to the Appointment Location
                    Determine the number of calories that will burn in the time from User's Current Location to the Appointment Location Using Equation (2)
                ENDFOR

Generate and Display personalized physical activity advice to the user to go to the appointment and a notification about the amount of burnt and remaining calories that must burn to reach the goal

ENDIF

ELSE

Determine the number of calories that will burn in the time period assigned to the next advice Using Equation (2)

IF Current Weather is suitable

Generate and Display personalized physical activity advice to the user (indoor/outdoor) and a notification about the amount of burnt and remaining calories that must burn to reach the goal

ELSE

Generate and Display personalized indoor physical activity advice to the user and a notification about the amount of burnt and remaining calories that must burn to reach the goal

ENDIF

ENDIF

SAVE user’s choice (if any) in user’s profile

ELSEIF User’s Current Calories Expenditure User’s = Optimal Daily Calories Expenditure

Display an encouraging notification including the amount of calories burnt “Congratulations! You reach your goal today to burn < User’s Current Calories Expenditure > calories”

Break REPEAT-UNTIL Loop

ELSE

Display an encouraging notification including the amount of extra calories burnt “Awesome! You exceed your goal today by burning extra <User’s Current Calories Expenditure - User’s Optimal Daily Calories Expenditure > calories”

Break REPEAT-UNTIL Loop

ENDIF

UNTIL end of the day

SAVE day data in user profile for future references

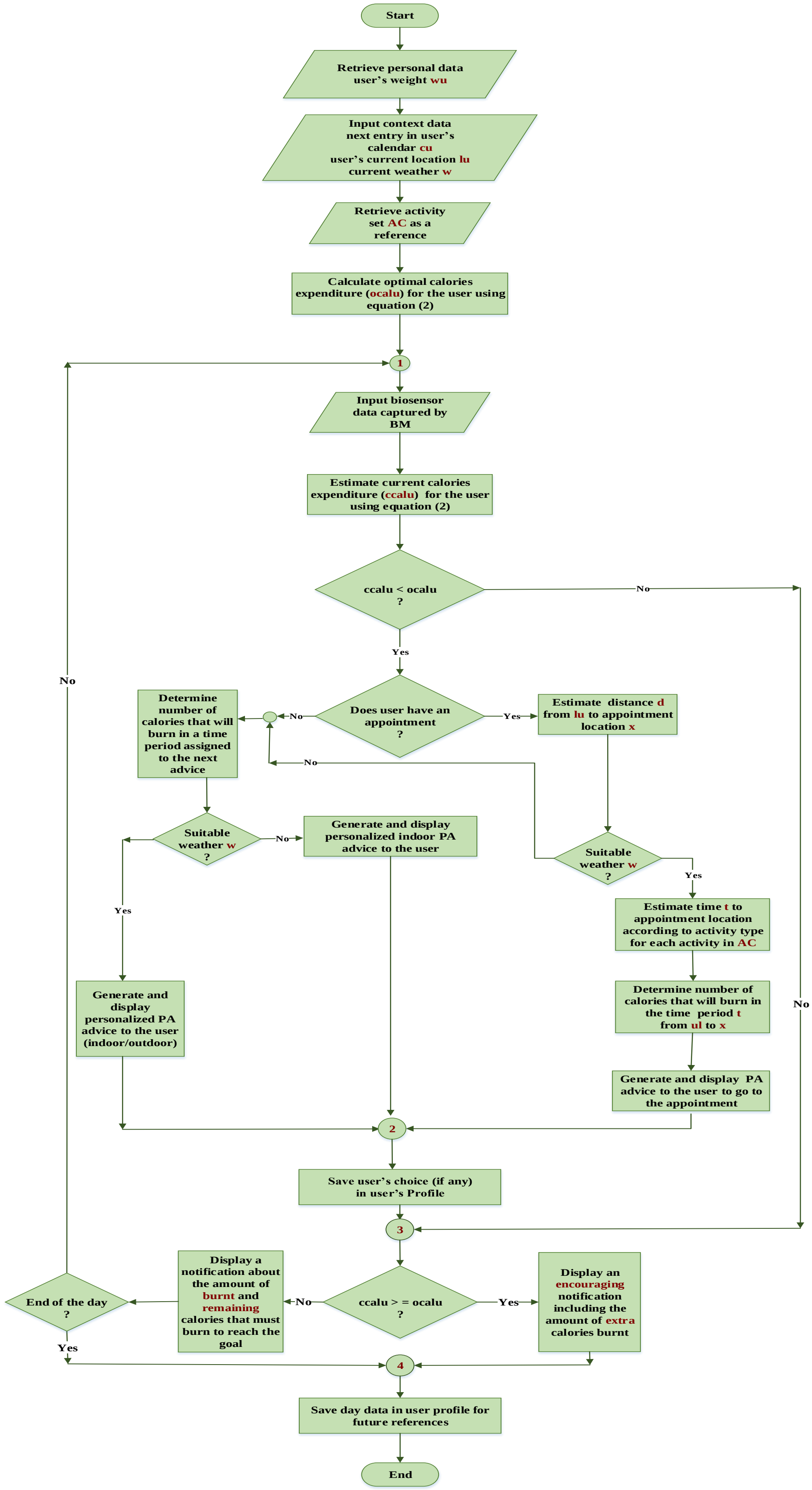


Figure 3.3 Physical Activity Advisory (PAA) Algorithm Flowchart

3.5 System Overview

We developed a Context-Aware Biofeedback (CAB) physical activity advisory system as a proof-of-concept for the proposed algorithm PAA and the extended UB reference model explained in the previous sections. The main purpose of this system is to promote a healthy lifestyle and improve physical activity level by increasing user's awareness about calories burned through providing personalized physical activity advice. This purpose is accomplished by tracking user's calories/energy expenditure and providing a personalized experience by using context-awareness, which employs the user's environmental context to provide suitable advice for the current time and place, which in turn encourages users to follow the provided advice. Figure 3.4 illustrates a high-level block diagram of the proposed system. The provided advice aims to increase the user's physical activity level and motivate him/her by using calories expenditure as a motivational factor. In specific, this involves tracking the amount of burnt calories and the amount of calories remaining to be burned according to user's weight, location, favorite locations and sports, schedule, and weather. The system flowchart is shown in Figure 3.5. Also, we designed CAB system to be a mobile system, which means it is adoptable to any type of computer device, such as personal computers, portable computers, smart phones, or any mobile device, as long as it is compatible with the software module requirements.

The proposed system works as the following:

The system starts its work by one time process, which is creating user's profile. It asks the user to insert his/her personal data, location preferences and favorite activities. Then, it calls the Physical Activity Advisory Algorithm, that performs system's function which is generating and displaying a personalized PA advice with multiple activity choices to the user. Choosing an activity in our system is an optional task since the amounts of calories expenditure with the next advice will reflect whether a user follows the advice or ignores it but in case he/she made a choice, the system saves the choice in the user profile for future references regarding user's favorite activities.

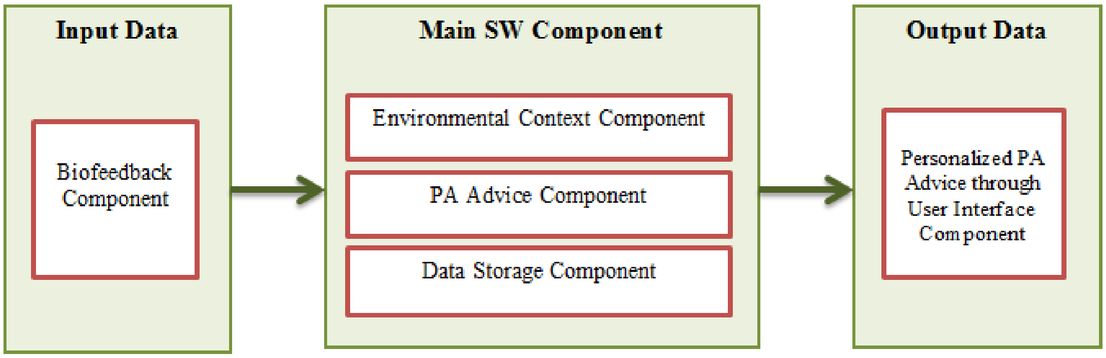


Figure 3.4 A high-level block diagram of the proposed system CAB

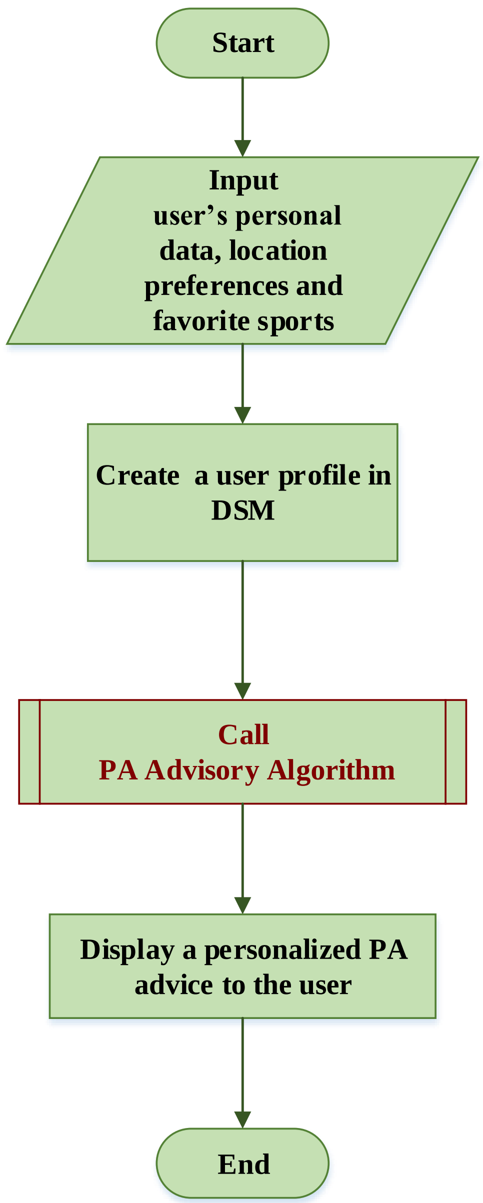


Figure 3.5 System Flowchart

3.6 System Architecture

In this section, we provide an overview of the system architecture. Figure 3.6 depicts an overview of the architecture of the proposed system, showing it comprised of two main components: the Hardware Component and the Software Component. The Hardware Component also consists of two modules: the Biofeedback Module (BM) and a User Interface Module (UIM). The Software Component includes three modules: the Environmental Context Module (ECM), the Data Storage Module (DSM), and the Activity Advisory Module (AAM). The BM contains biosensors that are used as a physical input interface to the system. The AAM contains PAA algorithm that is responsible for processing the data received from BM with the support of the DSM and ECM. The data source is biological data captured from physiological changes in user's body. For example, this could be user's heart rate data or acceleration data of the user's physical movements. The suggested advice is displayed on the user interface as a multimedia output: visual, audible, and haptic feedback. Finally, the system stores user responses to the advice in the DSM for future reference. Actual prototype implementation and technical details for the proposed system are explained in Chapter 4.

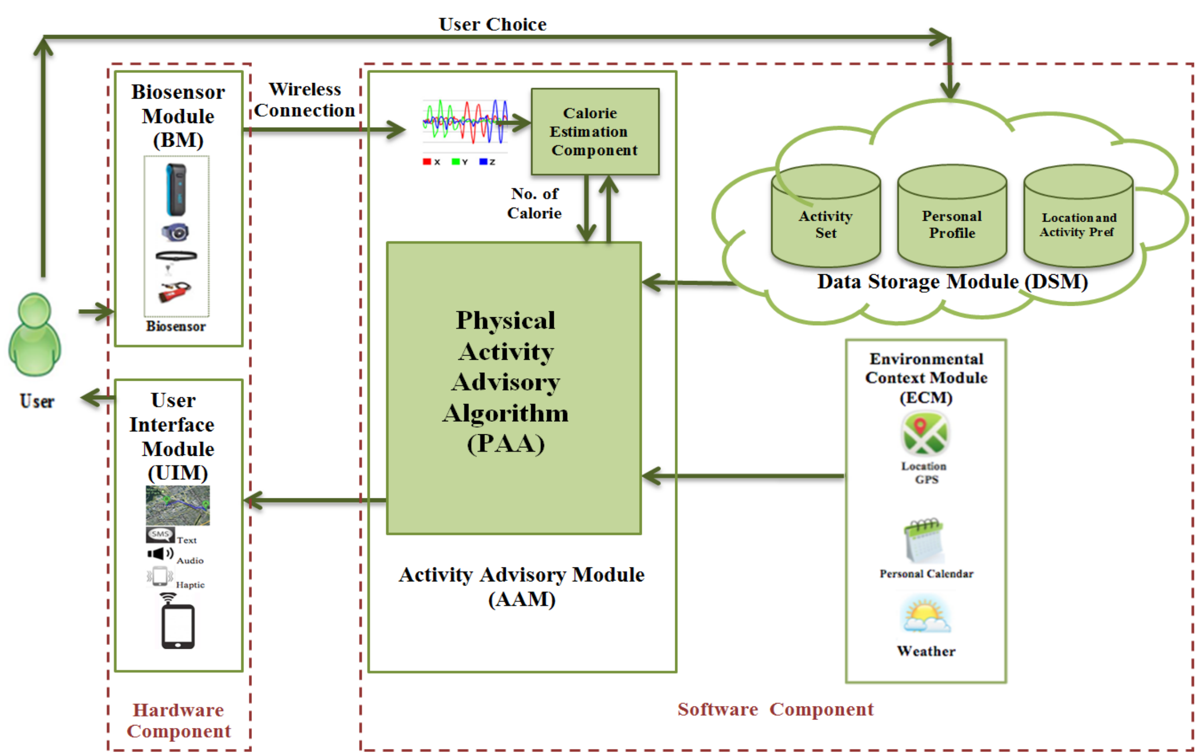


Figure 3.6 The Proposed System

3.7 System Component

This section describes in details the components of the proposed system, which are illustrated in component diagram shown in Figure 3.7. The following is a description of the two main components with their modules:

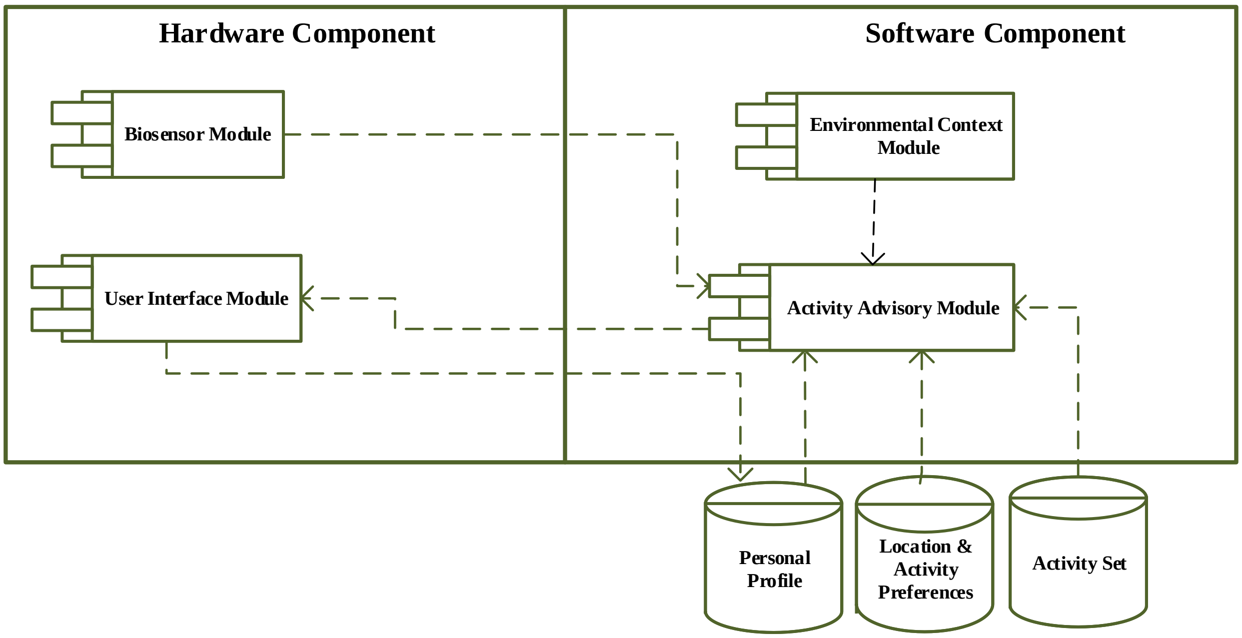


Figure 3.7 Component diagram of the proposed system

3.7.1 Hardware Component

This component contains two main modules as follows:

1. **Biofeedback Module (BM)**

   This module is responsible for tracking and capturing biological changes in the user's body. Some of this data is used to determine the amount of energy expenditure by the body. These data sources could be the heart rate, oxygen consumption, body temperature, or physical posture and movement. Determining the amount of energy expenditure is the starting point for our solution. In our proposed system, we chose to use an accelerometer to collect data about the user's physical movements and feed this data wirelessly as an input to the AAM in the Software Component. It is worth mentioning that the questionnaire results encouraged us to deploy this technology in our proposed system because the percentage of users accepting biosensor usage is 68%, as mentioned in section 3.1.2.

2. **User Interface Module (UIM)**

This module is responsible for notifying and interacting with the user by displaying the activity advice and receiving the user's response, storing it back in the DSM. Based on the interview results, we decided to notify the user about the advice in a multimode manner: visual, audible, or haptic notifications. Visual notifications provide advices as textual messages on a mobile screen through interactive GUI, and audio advice starts simultaneously with the advice trigger. The haptic feedback appears both in the form of vibration in the mobile device and in a chair where the user is seated, using a haptic chair mentioned in [46].

3.7.2 Software Component

This component contains three main modules as the following:

1. **Environmental Context Module (ECM)**

This module is responsible for supporting the AAM, which is the core module in our system, to provide appropriate PA advice with regards to proper timing and surrounding environmental conditions. Based on the results of the questionnaire, we selected weather, calendar (agenda), and current location as context data sources. Environmental context data are used by PAA to check the suitability of the location. The weather and the calendar are used to provide the advice at a proper time and appropriate place.

2. **Data Storage Module (DSM)**

This module is responsible for storing all data received by the system, either from hardware component modules or software component modules in the cloud. We designed our system to include three data stores in the DSM. They are the Personal Profile Data Store, the Location and Activity Preferences Data Store and the Activity Set Data Store. The Personal Profile Data Store contains all users' data, identifying each user with a unique number. These data include personal data, such as name and weight, in addition to user's choices history. The choices history is used for future reference and can show the last day, last week, and last month's selections. The Location and Activity Preferences Data Store is used to store each user's favorite locations and sports in different environments (home and work). The Activity Set Data Store is used to store a set of basic physical activities, such as walking, which are mapped to their MET values.

3. Activity Advisory Module (AAM)

This module is the core part and our main contribution in this system. It consists of two main parts: Calorie Estimation Component and PAA algorithm. Calorie Estimation Component is responsible about calculating energy expenditure according to the collected biological signals from the user's body using calorie estimation formula in [4, 26]. The outcome of this component, which is the number of calories, is fed to the PAA algorithm. This algorithm is the heart of the proposed system and it explained in details above in Section 3.4. Generally, it completes its task by retrieving data from the DSM and ECM. It then provides context-aware activity advice based on a user's energy expenditure, context, and preferences. The provided advice is displayed through UIM.

3.8 Use Case Diagrams

The main use case diagram for using the proposed system is shown in Figure 3.8 The use cases interact with one primary actor, the system user, to represent the main goals of the proposed system.

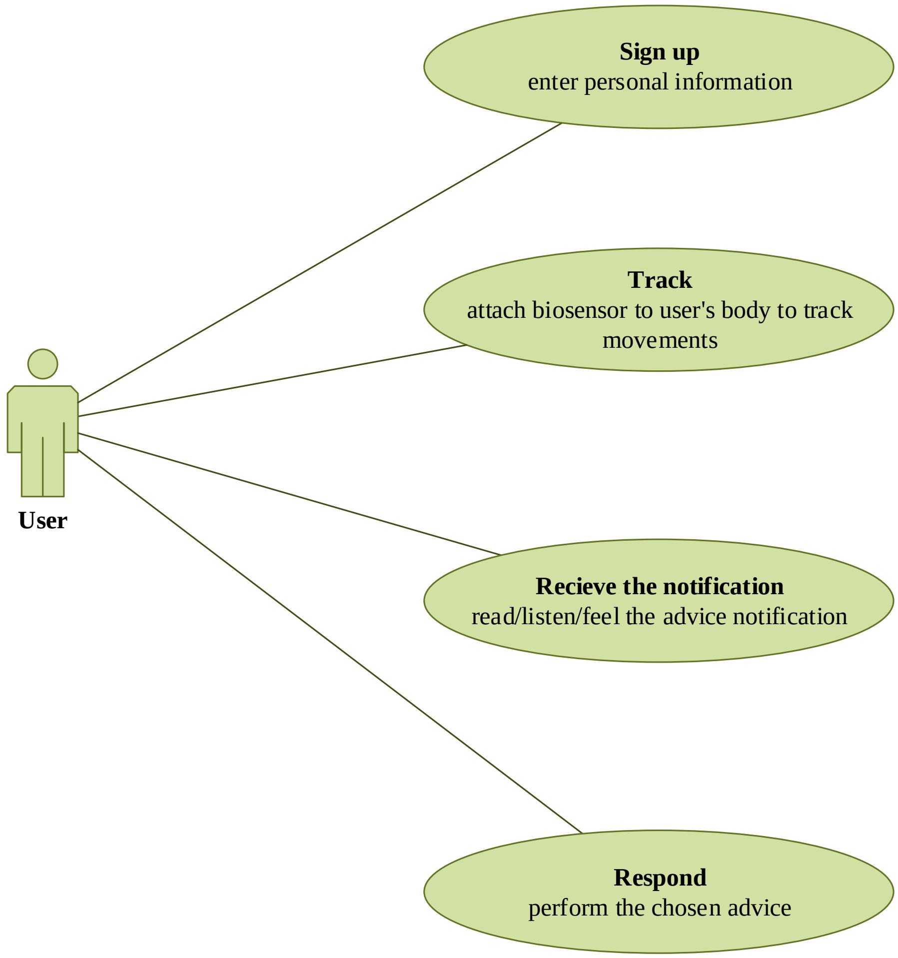


Figure 3.8 External User Use Case: High Level View of the Main Use Case

Actor: User

Description:

The system provides the following key functionalities to its primary user after attaching the biosensor to his/her body:

- Sign up by entering personal information, especially weight
- Attach the biosensor to his/her body to track movements
- Receive the notifications to perceive (read/hear/feel) the advice
- Respond to the advice

In addition, the internal functionalities of the Activity Advisory Module are illustrated in Figure 3.9.

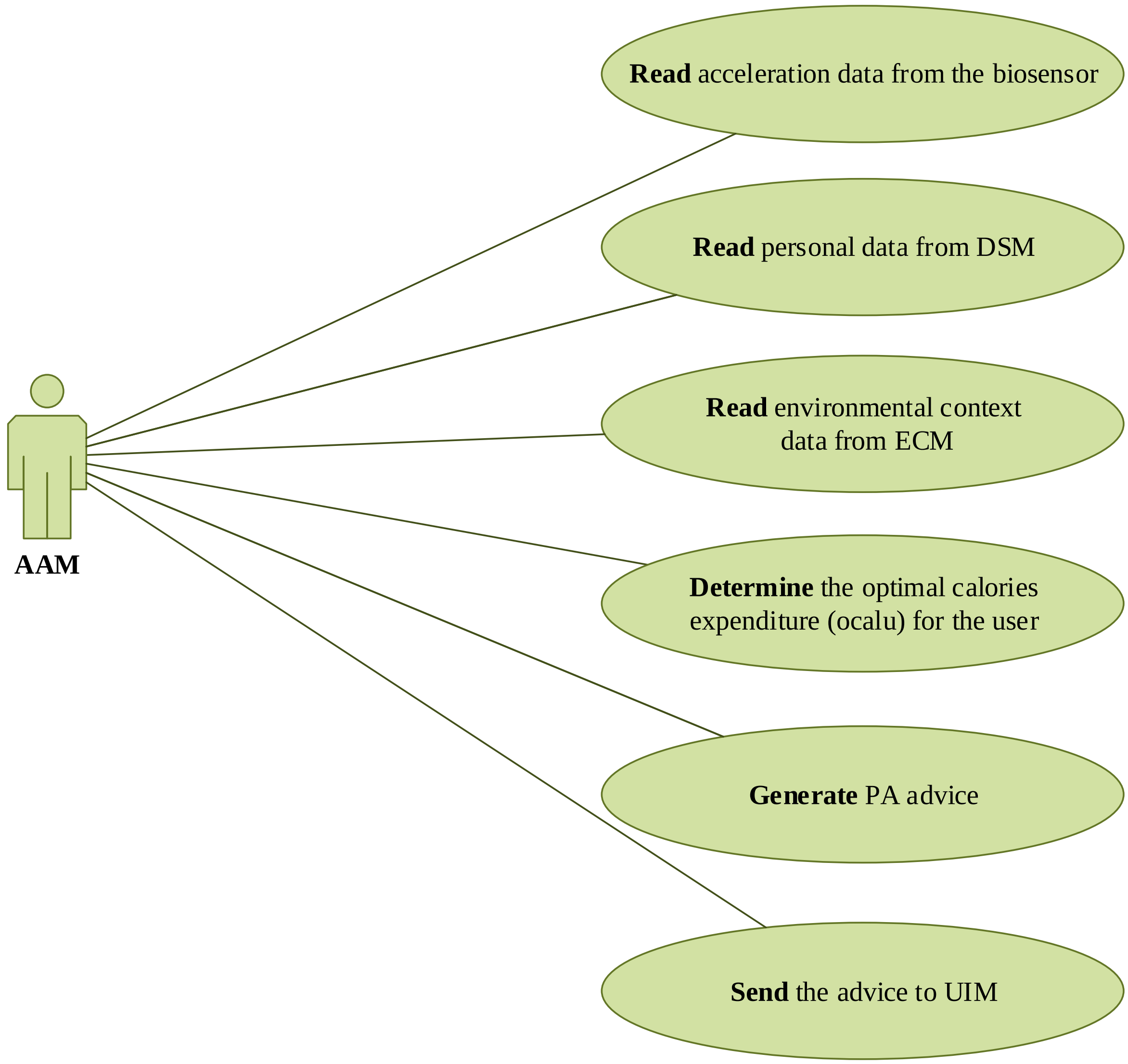


Figure 3.9 Internal Use Case: Activity Advisory Module (AAM)

Actor: Activity Advisory Module

Description:

The Activity Advisory Module performs the following key functionalities with the support of other modules/ subsystems to provide advice:

- Read acceleration data from biosensor in Biofeedback Module (BM)
- Read personal data from Data Storage Module (DSM)
- Read environmental context data from Environmental Context Module (ECM)
- Determine daily optimal calorie expenditure
- Generate physical activity advice

- Send PA advice to the User Interface Module (UIM)

3.9 System Scenario

The suggested scenario of data flow in our system is depicted in the sequence diagram shown in Figure 3.10

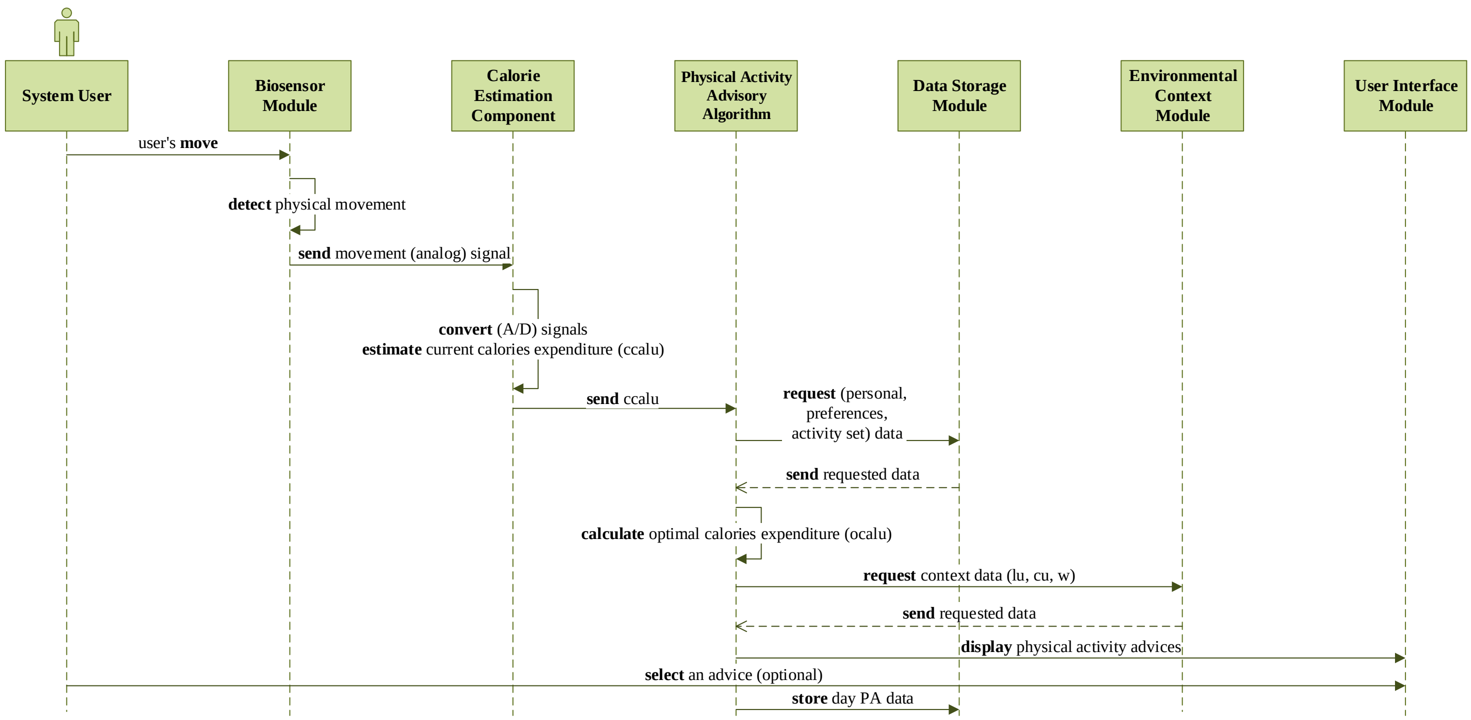


Figure 3.10 System Sequence Diagram

Chapter 4

Implementation

In this chapter, we discuss in detail the hardware and software components that we used in the developed prototype. Section 4.1 provides information about the hardware devices integrated in the system. Explanations of the software modules, graphical user interfaces, and application programming interfaces (APIs) are provided in Section 4.2. Finally, section 4.3 gives a detailed description of system scenarios through the experience of one of the participants during a system evaluation.

4.1 Hardware Component

The CAB Activity Recommending Application hardware component consists of two main devices: a biosensor and a smartphone. The biosensor was chosen based on its adequacy as a comfortable companion for the user while he/she moves. Also, we chose a smartphone as the main interaction medium and tangible user interface between the user and the system to guarantee the mobility feature for the developed system, although our system prototype was first developed on a personal computer. The hardware used in the prototype development is as follows:

1- A Biofeedback Sensor

The accelerometer is the biosensor that we used in our proposed system. It tracks the user's physical movements by collecting the 3D data and sending them to the system. In fact, there are several activity monitoring devices available in the market, but we used an activity tracker called Fitbit [28], which has a built in accelerometer. There are several reasons for choosing Fitbit from among the existing activity trackers. First of all, Fitbit is characterized by its accurate tracking of the user's physical movements comparing to other trackers in the same price range since it includes a 3D motion sensor like the one found in the Nintendo Wii [47]. Also, the Fitbit device has a wireless synchronization feature that enables real time updates for user profile in Fitbit website using Bluetooth 4.0 [25, 28]. Moreover, Fitbit trackers open the door for developers to use collected data in different applications under the regulations of the Fitbit API with full on-line support for the developers [48]. In addition, it has long battery life and an online application for tracking the user's daily activities. Fitbit is also considered to have a reasonable price and the most features for that price compared to all other trackers. In addition, Fitbit is a user-friendly and easy-to-use tracker that does not annoy a user since it can be worn on several locations on the body. They are compatible with most popular operating systems and platforms, such as iOS, Mac, PC and Android. Figure 4.1 depicts the Fitbit activity monitoring devices that we used in our system. In fact, we used two different products: Fitbit Ultra and Fitbit Zip.

(a) Fitbit Ultra

(b) Fitbit Zip

Figure 4.1 Hardware used in system implementation

2- User Interface

In the early stages, we developed the prototype of our proposed system using a regular personal computer, where we developed our application using Google Drive spreadsheets and Google Developer scripts. Then, we used Android smartphones (Samsung Note II, Samsung S3 and Samsung S4). While we were developing and testing the system on the PC, we were using the base station that comes with the Fitbit Ultra device for synchronization. Figure 4.2 shows the base station during the development process [47]. Then, we used Fitbit Zip because it provides wireless synchronization with the smartphones.

Figure 4.2 Fitbit Ultra base station

4.2 Software Modules and APIs

On the software application side, the proposed system has been developed using Google Developer scripts on Windows 7 and Android platforms. Another two applications have also been incorporated in the system software to support the system's functionalities. The APIs and system features can be described as follows:

4.2.1 Fitbit API

The Fitbit API [48] enables developers to utilize Fitbit data in their applications. It supports read and write methods to be used by developed applications and services. In order to have access to this API, the developer just need to create an account in the Fitbit Developers website and register his/her application, provide required information about it, specify the access type, and agree on the terms of service. This provides the developer with the Consumer Key and Consumer Secret Code for the application. Once he/she has completed the registration process, he/she will have access to Fitbit data and can manipulate them to serve his/her application or service. Figure 4.3 shows a screenshot of our system application on the Fitbit developer website.

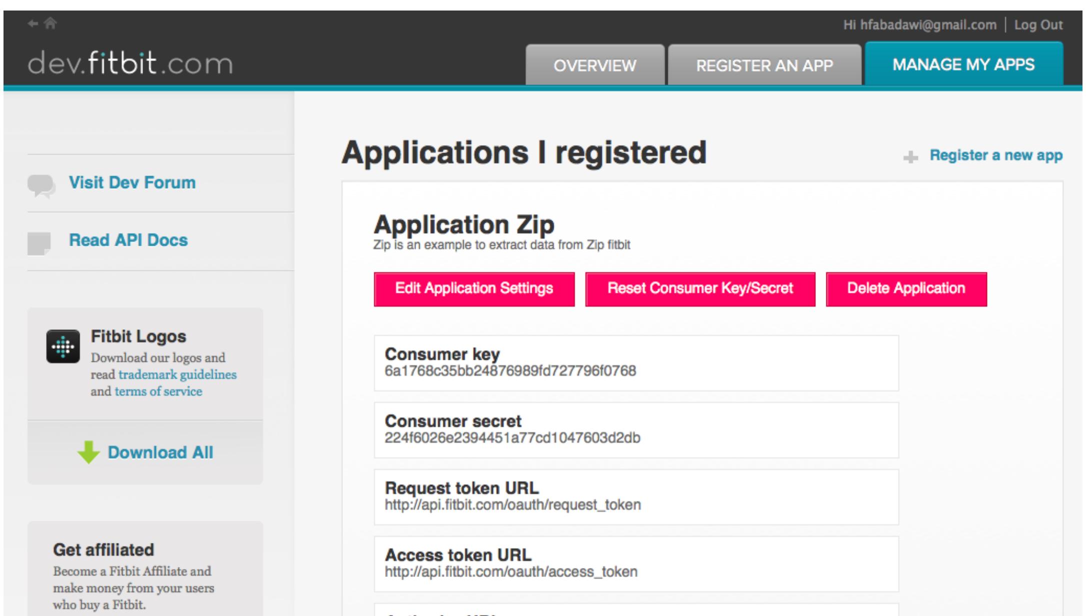


Figure 4.3 Our system registration at the Fitbit developer website

4.2.2 Google Developers

Google Developers [49] is considered to be one of the leading API providers in the programming world since it provides many APIs that enable different functionalities. When we were working on developing the prototype of our proposed system, we used spreadsheets in Google Drive, where we created several sheets as storage for our system's data that can be accessed by Google Developer scripts to manipulate collected data.

4.2.3 Push Data Application

This is a publicly available application that was developed previously under GNU General Public License version 3 (GPL-3.0). It pushes tabular data between spreadsheets on time-based triggers [50]. We utilized this application in order to push activity data such as number of calorie, which is collected by the Fitbit device to the spreadsheet in our project folder on Google Drive in order to update the system's data on an hourly basis. The synchronization is performed wirelessly every 15 minutes from the device to the system, and pushing the synchronized data is performed every 1 hour. Therefore, our system is triggered by pushed data on an hourly basis, but we decided to make the notification every three hours based on tracking experiment results which show a slight difference from hour to another in the number of activity calorie.

4.2.4 Distance Calculator Template

To calculate the distance from a source to a destination we adapted a spreadsheet template developed by [51] that makes use of the Google's geocoding API for distance calculations. In order to use this template, a user needs to fill out "From" and "To" locations and the spreadsheet calculates the distance and the required time based on the recommended route. This template enables the user to choose region, language, measuring unit (miles or kilometers) and mode (walking, bicycling and driving). In addition, this template has the ability to add results to a trip log spreadsheet and this is the main feature that motivated us to use this template.

4.3 System Scenario and Graphical User Interfaces

This section presents the scenario for CAB Activity Recommending Application, with the associated GUIs in sequence. The presented scenario (Jolia's scenario) shows that we considered weather and location as sources for environmental context data in the implemented prototype. This scenario is shown through advice types according to the time of the day. CAB homepage and login GUIs are shown in Figure 4.4 follows by Jolia's scenario with GUIs.

(a) (b) (c)

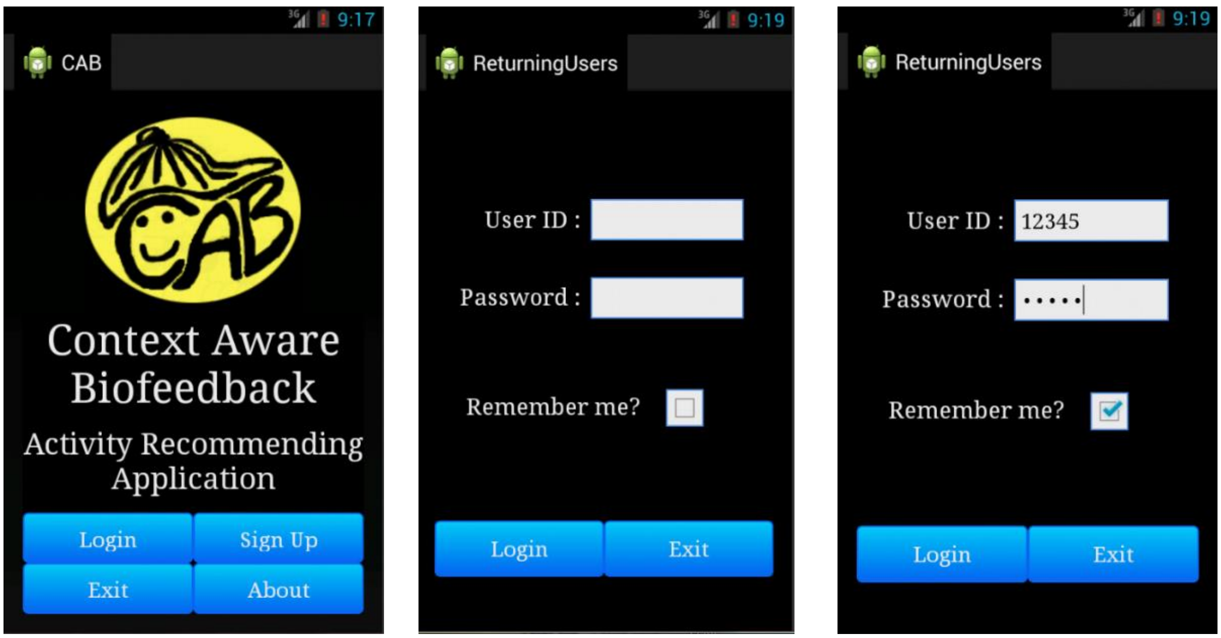


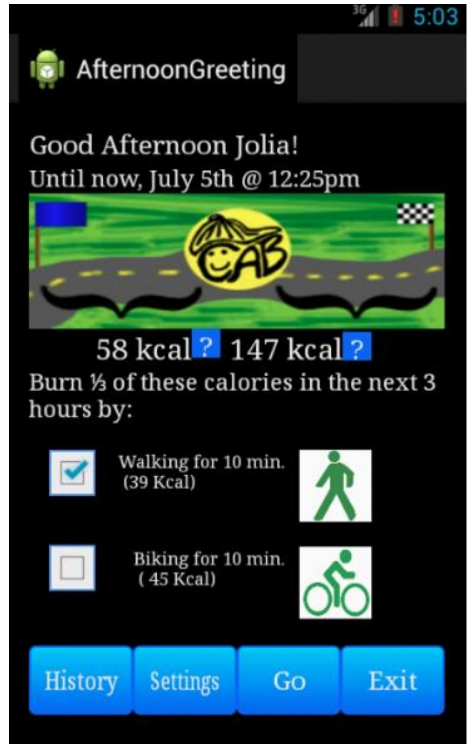
Figure 4.4 CAB system homepage (a) and login GUIs: (b) and (c)

- **Jolia's Scenario:**

Jolia is an undergraduate student and she spent most of the day at SITE Building, University of Ottawa. Her weight is 65 Kg and she owns a bicycle, which she uses when the weather permits to come to the university. Table 4.1, explains PAA algorithm case that we considered in the system implementation and evaluation through Jolia's experiment. The table shows the currently implemented CAB system, which sends three different types of advice to the user during the day in addition to a reporting/notifying advice, which aims to notify him/her about his/her performance by the end of the day. These advices are separated by a minimum time frame of 3 hours to cover the working day period.

Besides, Table 4.1 illustrates screenshots of advices during Jolia's experiment with the system to better understand advice types where she received 3 advices per day in addition to the reporting advice for one business week. Jolia's experiment is explained in detail in Chapter 5.

Advice Type	**Screenshot**
Morning Advice: This considers the daily starting point of the advisory process, where advice is sent one hour prior to when the user must be at work. It considers the work route in its content along with the transportation method. As a morning greeting, the system informs and reminds the user about the amount of calories that should be burned that day through physical activity.	

Advice Type	Screenshot
Midday Advice: This suggestion is sent around the lunch break hour. It considers the work environment and surroundings and gives the user a notification about the calories that have been burned that day and how much they need to burn in order to reach the daily target. This advice encourages the user by giving the suggestions that will minimize the remaining calories in order to achieve the daily target.	
End of the Working Day Advice: This is sent one hour prior to the end of the working day. This advice considers both work surroundings and the route home. Like the previous advice, it encourages the user by showing how following the provided advice will minimize the remaining calories needed to be burned in order to achieve the daily target. It hints of being close to the end of working day in order to motivate the user to follow the provided advice.	

Advice Type	Screenshot
Reporting/Notifying Advice: This is sent after the end of the working day as a report of the working day's physical activity level. It expresses the user's physical activity status and encourages the user through one of three cases: the "Awesome Case", when he/she exceeded the daily recommended calories expenditure, the "Good Job Case" when he/she burns the daily recommended calories expenditure, or the "Be Active Case" when he/she does not burn the daily recommended calories expenditure.	

Table 4.1 Advice types and screenshots of the implemented system

Chapter 5

Evaluation

In this chapter, we present the evaluation of the proposed algorithm PAA and the extended UB reference model through evaluating CAB system. The system was evaluated by tracking the physical activity level of a group of adults, monitoring the calories burned from following the provided advice (Quantitative Evaluation) and checking the system usability by asking participants for their opinions about the proposed system (Qualitative Evaluation). The evaluation criteria for our proposed system are explained in section 5.1, which also interprets the meaning of "useful advice" from our point of view. Regarding the evaluation methodology, and settings, we set our evaluation plan by following the same evaluation approach in the most relevant work to our system Motivate [40, 41]. A comparative study between our evaluation settings and Motivate [40] settings, the experimental setup, and the procedure are mentioned in Section 5.2. In Section 5.3, we present the quantitative evaluation for the proposed system. The qualitative evaluation, represented by the questionnaire results, is presented in Section 5.4. Finally, we conclude this chapter with a results discussion in Section 5.5.

5.1 Evaluation Criteria

To assess the proposed system as a proof-of-concept for the proposed algorithm PAA and extended UB reference model, we made an evaluation that aims to determine whether the system provides useful advice or not. In fact, we introduced the following criteria that describe the factors of "useful advice" from our point of view:

1. **Standard Advice:** This is a determination of whether the provided physical activity advice meets the recommended amount of physical activity required daily for maintaining a healthy lifestyle.

2. **Biofeedback Advice:** This is a determination of whether the provided physical activity advice considers the user's physiological status regarding the calories burned, and displays it to the user in a form of a biofeedback value according to UB Reference Model [2].
3. **Personalized Advice:** This is a determination of whether the provided physical activity advice considers the user's context, including the environmental context, the user's daily schedule, and the user's preferences regarding favorite physical activities and locations.
4. **Easy-To-Do Advice:** This is a determination of whether the provided physical activity advice is considered easy to follow from the user's point of view.
5. **Multimedia Output:** This is a determination of whether the multi-mode notification for the provided physical activity advice is effective in notifying the user. In our implementation and evaluation, we accommodated the visual notification style in the form of textual messages provided to the users through a GUI on their Android phone.

5.2 Evaluation Setup and Procedure

5.2.1 A Comparative Study

This section shows the similarities and differences between our proposed system CAB and Motivate system with regards to how the systems were tested. Table 5.1 illustrates the comparison, including comments for additional clarification.

Criteria	CAB System	Comments for CAB System	Motivate	Comments for Motivate System
Similarities				
One-time setup for user account	✓		✓	
PA advice sent to mobile phone	✓		✓	
Number of PA notifications/day	3		3	
Evaluation: tracking the user in the first week without sending advice	✓	Tracking the number of calories burned in 5 business days	✓	Tracking the location coordinates in 5 business days

Criteria	CAB System	Comments for CAB System	Motivate	Comments for Motivate System
Evaluation: conducting after-experiment interview	✓		✓	
Differences				
Frequent modifying of user's profile	Optional	To modify favorite activities and places	Mandatory	To update user's agenda on a daily basis
PA advice contains multiple activities	✓	It gives two choices: user's favorite activity as a first choice and another activity as a second choice	×	It considers walking as the only activity
User must check the system frequently for advice	×	Advice sent automatically because of continuous synchronization	✓	Users must check the system manually for new advice
System needs a response	Optional	To check user's choice not his/her response to the PA advice because the number of calories at the beginning of next advice will reflect if the user follow the advice or not.	Mandatory	To check if the user will take into account the provided advice since there is no other way to discover his/her choice

Table 5.1 A Comparison between CAB (our system) and Motivate

5.2.2 Experimental Setup and Procedure

In order to evaluate the proposed system, we conducted our experiment, which targets the working day that is defined as 8 hours long [24], on 6 participants (3 males and 3 females), and all of them work in an office environment. We assume that our two-weeks experiment conducted under the same conditions. We started with a pre-experiment interview.

For each participant, we started with an introductory session where we:

- Introduce the system and explain its function
- Explain how to use the activity tracking device, Fitbit

- Explain what the participant should do in order to guarantee the continuous synchronization of the device with the system
- Explain how to download the Fitbit setup
- Provide the Google account that is used to collect tracking data

We then asked each participant about: weight, working hours (start and end hours of the working day), favorite physical activity (the two most preferable activities), home address, work address, commuting method (walking, biking, bussing, or driving a car), and favorite places (gym, walking area, park, shopping mall, etc.). After that, the experiment started sequentially for one participant at a time. We tracked the user's calorie expenditure count from performing different physical activities for one week before using the system in order to estimate the physical activity level of each participant through the amount of calories burned and compare it to the optimal calories expenditure for this participant. During the next week, the physical activity tracking process continued, but the system started to send the three different types of advice in addition to the reporting advice each working day and compare the amount of calories burned to the optimal calories expenditure.

5.3 Quantitative Evaluation

We conducted our experiment on the 6 subjects to fulfill the following objectives quantitatively.

5.3.1 Evaluation Objective

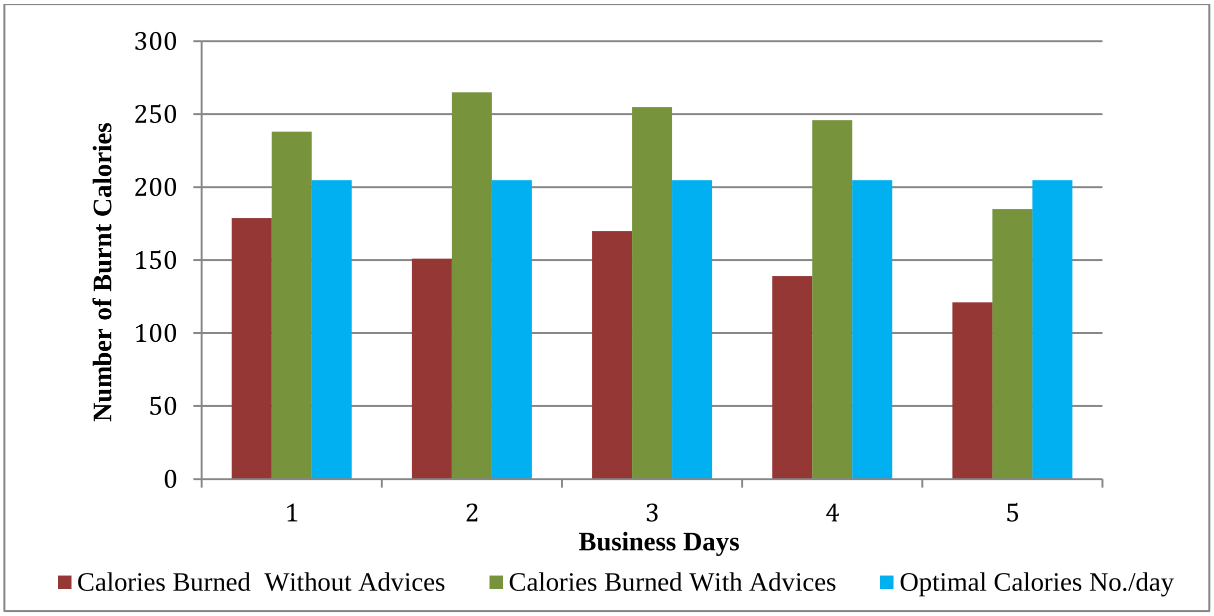
The above-mentioned experiment aims to:

1. Observe participants' physical activity levels before and after interactions with the proposed system CAB by comparing the amount of calories burned with the optimal calories expenditure to maintain a healthy lifestyle.
2. Observe any improvement in the participant's physical activity level
3. Observe the effect of biofeedback, represented as the amount of calories burned, as a result of following the provided advice
4. Observe the impact of environmental context on the advice efficiency

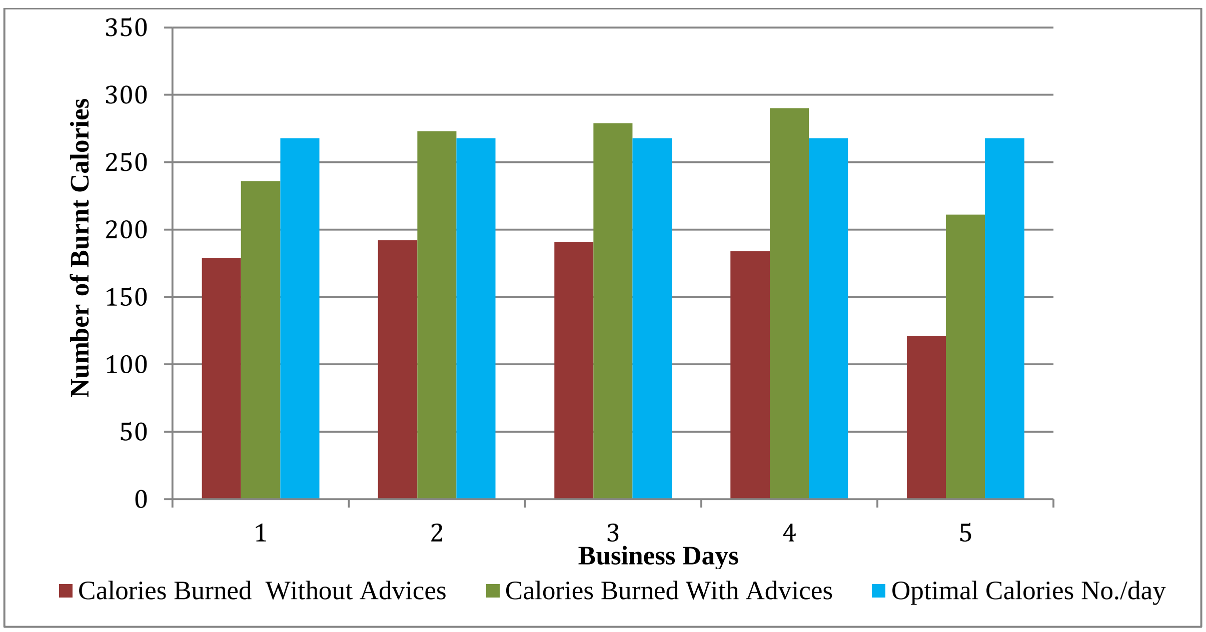
5.3.2 Results

Subjects' Interaction: Participants reflected their acceptance for the idea of the proposed system through high-level interaction with the provided advice, especially after following the advice and noticing the improvement in the amount of calories burned and in their activity level in general. They show a special interest in knowing the number of calories burned from performing the different physical activities. They commented that knowing the number of calories motivated them to follow the suggested activities because it gives the impression that the provided advice is personalized and targeted to each participant separately. Also, they like the idea of considering the favorite activities in the suggested activities, in addition to considering the environmental conditions like weather and location.

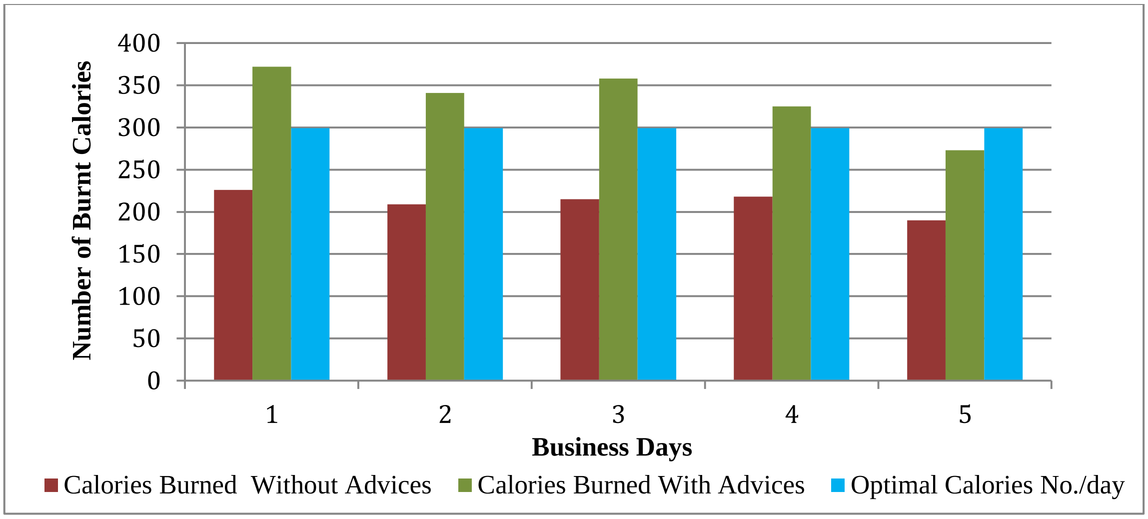
Improving Physical Activity Level: It was noticeable that the physical activity levels of participants improved after comparing their physical activity level by comparing the amount of calories burned with the optimal calories expenditure during the first week before using the system and that during the second week while using the system. Figure 5.1 shows the overall improvement of the physical activity level of each participant compared to the optimal calories expenditure during the two-business week period. Each figure shows the amount of calories burned without advice (week 1) and the amount while following the advice (week 2) compared to the optimal calories expenditure. This reflects the physical activity level before and after using the system. Figure 5.2 shows the average number of burnt calories for all six subjects compared to the optimal calories expenditure. Also, Table 5.2 shows the optimal amount of calories that each subject needs to burn daily and weekly, the actual amount of the calories that each subject burned weekly before and after using the system, in addition to the percentage of improvement in the physical activity level.



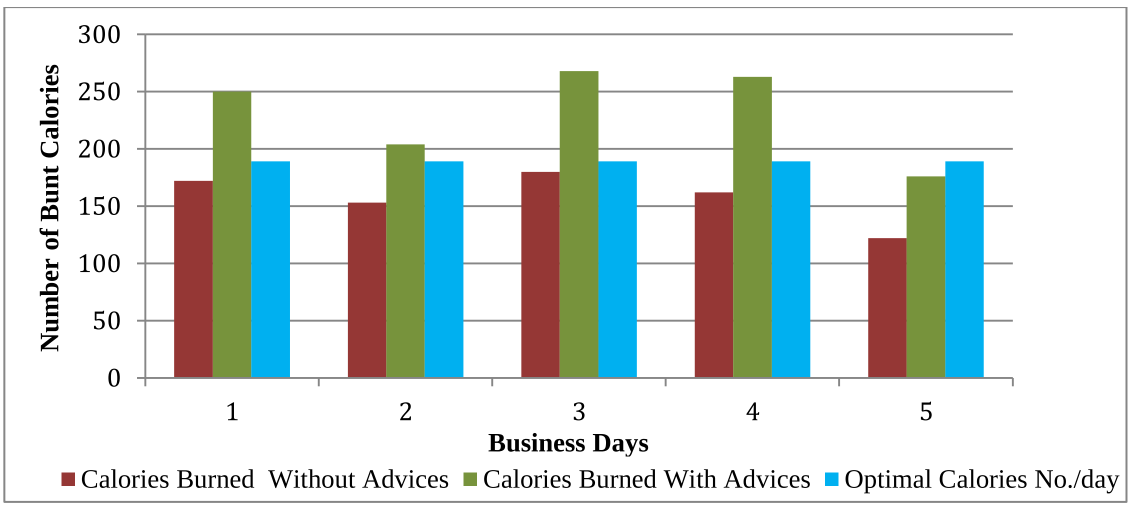
(a) Subject 1



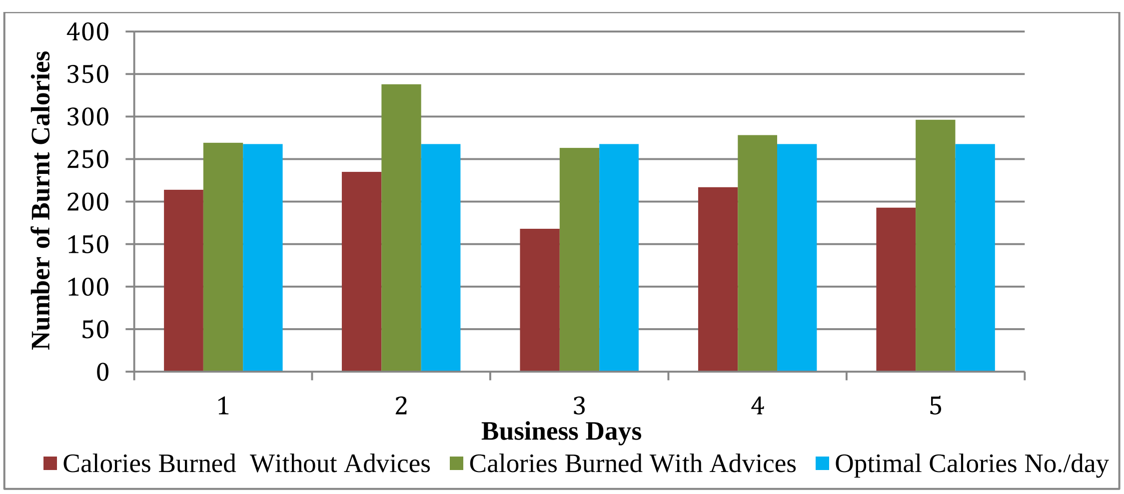
(b) Subject 2



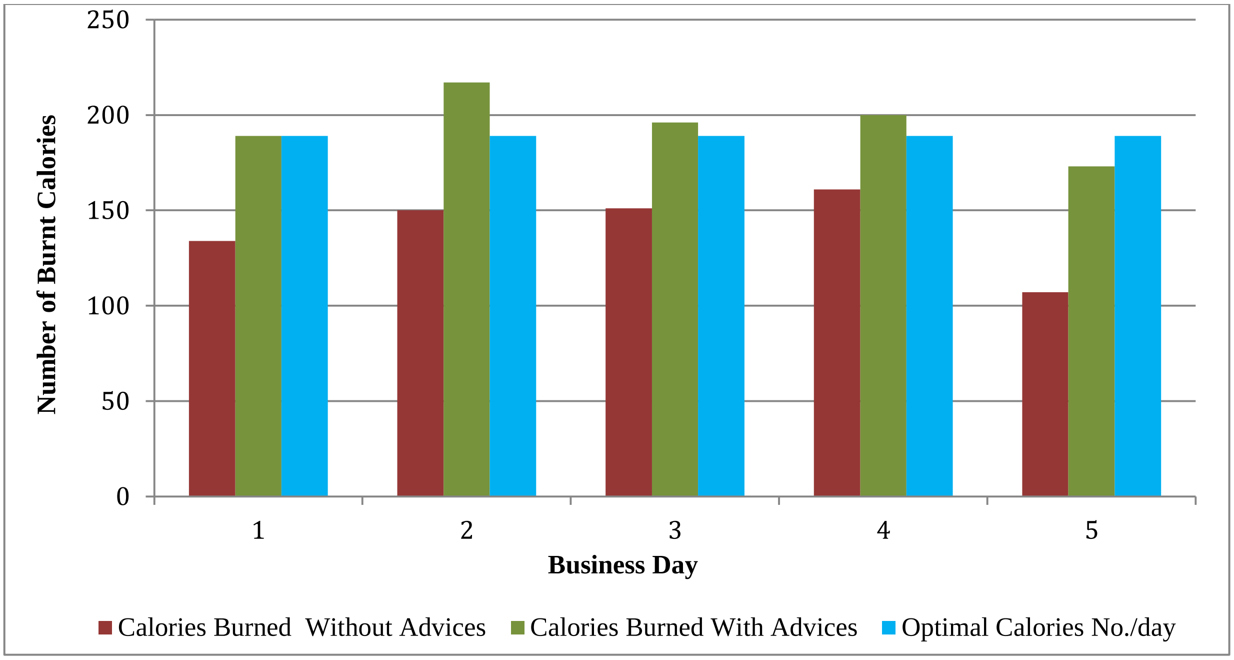
(c) Subject 3



(d) Subject 4



(e) Subject 5



(f) Subject 6

Figure 5.1 Number of calories burnt along five business days before and after each participant followed the advice the CAB system proposed

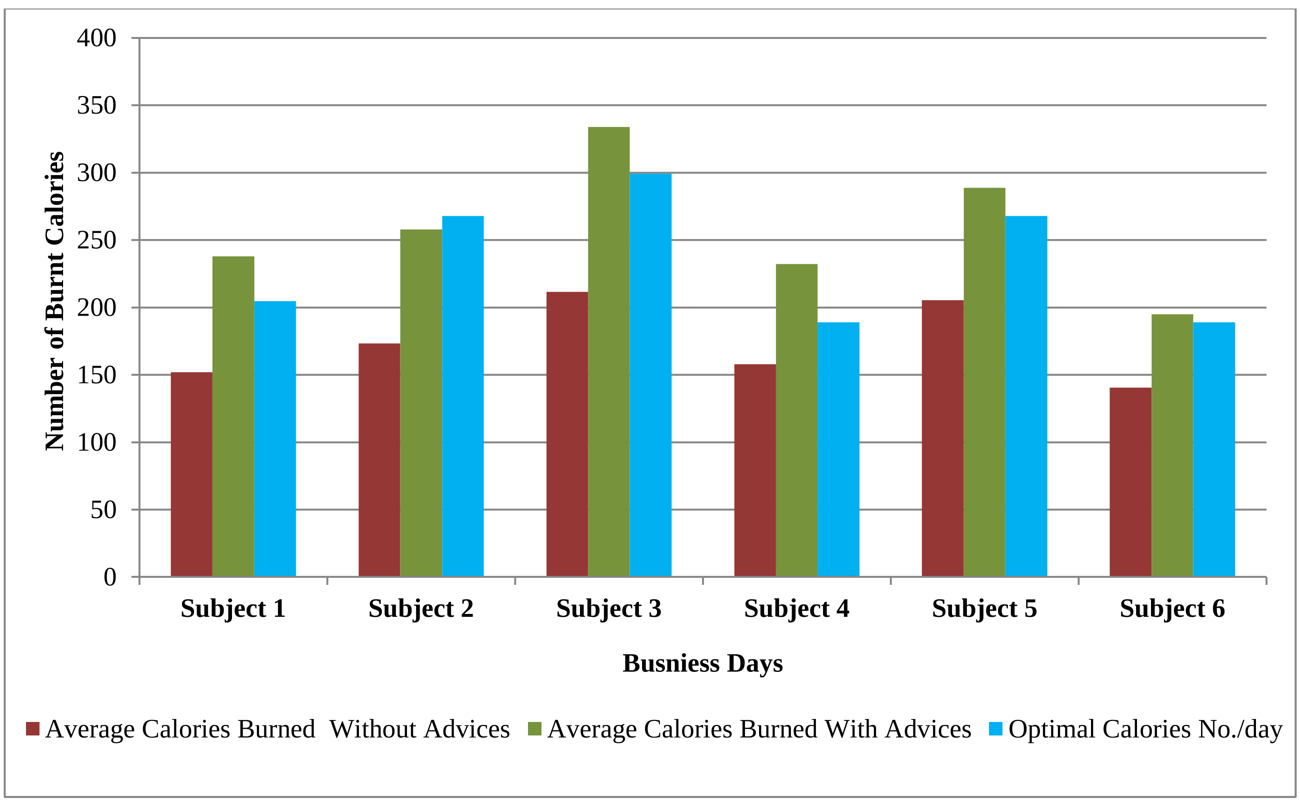


Figure 5.2 Average number of burnet calories for all subjects

Comparison Criteria	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Optimal number of calories that must burn / day	204.75	267.75	299.25	189	267.75	189
Optimal number of calories that must burn / week	1023.75	1338.75	1496.25	945	1338.75	945
Actual number of calories burnt / week without advice	760	867	1058	789	1027	703
Actual number of calories burnt / week with advice	1189	1289	1669	1161	1444	975
Percentage of calories burnt without advice / week	74%	65%	71%	83%	77%	74%
Percentage of calories burnt with advice / week	116%	96%	112%	123%	108%	103%

Table 5.2 Improvement in the physical activity level of participants when using the system

5.4 Qualitative Evaluation

In order to evaluate the proposed system qualitatively, we conducted a questionnaire that helped us to test the system's usability.

5.4.1 Evaluation Objective

The questionnaire aims to:

1. Evaluate the overall effect of the proposed advisory system on the physical activity levels of participants from their point of view
2. Evaluate the personalized advice by:
    a. Specifying the effect of the biofeedback feature represented in calories burned after following the provided advice
    b. Specifying the impact of environmental context on the efficiency of the provided advice
3. Evaluate participants' satisfaction with the system

Please refer to the Appendix B for the questionnaire questions.

5.4.2 Results

Participant responses reflect a positive impact of the system on their physical activity levels by helping them reach or exceed the minimum number of calories to be burned daily by the end of the working day. The Questions and participant responses are as follows:

- **Q1. Does following the advice provided by the system help you to be more active?**
  All the participants answered Yes for this question.
- **Q2. Evaluate the impact of the system on your physical activity level.**
  60% of them answered Very Active and 40% answered Active.
- **Q3. Does knowing the amount of calories that you need to burn daily make sense for you?**
  All the participants answered Yes for this question.
- **Q4. Does knowing the amount of calories that you need to burn daily motivate you to follow the provided advice?**
  All the participants answered Yes for this question.
- **Q5. Are location and weather important in the provided advice in order to encourage you to follow the advice?**
  60% of them answered Yes and 40% answered Neutral.
- **Q6. How do you evaluate your overall experience of using the proposed system?**
  60% of them answered Very Active and 40% answered Active.

5.5 Results and Discussion

From the above-mentioned results and charts, we can conclude that the physical activity level of the participants changed positively after responding to the provided advices, which proves the concept of PAA usefulness. Therefore, we believe that deploying the proposed algorithm PAA and the extended UB reference model in this thesis in physical activity advisory systems such as CAB has a potential impact on user's physical activity levels which in turn makes such systems a good example of the promising solutions for the physical inactivity problem. In fact, the proposed system CAB has a positive impact on the experiment sample group by motivating the participants to reach or exceed the minimum number of calories to be burned daily for most of the evaluation days. However, we still need to conduct the experiment on a larger size sample and for longer period of time.

Also, by comparing our final results with the results of previous work [40], we can say that utilizing the biofeedback feature, represented as the number of calories in the algorithm for generating physical activity advice, enhances participants' responses to the recommended advice, which in turns increases their physical activity level.

In addition, providing physical activity advice according to the environmental context has a significant effect since considering weather and user's location facilitate applying the provided advice.

Moreover, providing more than one choice of activity enhances the response percentage to the advice because it adds more flexibility and freedom for the user to pick an option instead of instructing him/her.

Finally, considering user preferences, which is represented in our implementation by giving priority to user's favorite activity, shows that this can be a motivational factor for the user to follow the advice.

Chapter 6

Conclusion and Future Work

In this thesis, we presented a possible solution for the global physical inactivity problem. We proposed PAA algorithm for biofeedback context-aware physical activity advisory system that aims to provide the user with personalized physical activity advice at a suitable time and proper location. Also, we extended the UB reference model in order to propose this algorithm. As a proof-of-concept for the proposed algorithm and extended UB reference model, we developed a system called CAB Activity Recommending Application as an Android application. It provides a user with several PA suggestions during the working day based on the amount of calories the user needs to burn. In Chapter 1, we discussed the urgent need for solving the global issue of physical inactivity, and we proposed our suggested solution for increasing physical activity level to maintain a healthy lifestyle. The related work and basic terminologies that we referred to while working on this thesis are presented in Chapter 2. In this chapter we also show what makes our system different from existing systems by presenting a comparison table. In Chapter 3, we discussed in details the proposed PAA algorithm, the proposed extension on the UB reference model to add context awareness component and the design of the proof-of-concept system for the proposed algorithm. The prototype implementation is presented in Chapter 4 with an explanation of the hardware components and software modules of the system. And finally, Chapter 5 presents the qualitative and quantitative evaluations of the system. They show positive results that promise a successful deployment of the proposed algorithm and extended UB reference model and their expansion with other systems. Also, the results show the efficiency of the developed application in increasing users' physical activity levels, starting by increasing his/her awareness of the calories being burned and providing environmental context aware advice according to this amount.

For future work, we plan to expand the application usage based on the proposed algorithm and extended UB reference model to be used for weight maintenance, which can contribute directly to obesity. Also, we plan to use the advisory system to help remind users to drink the recommended amount of water per day, which differs according to gender and other factors such as physical activity and diet [52]. Moreover, we plan to deploy the proposed algorithm and extended UB reference model to develop clinical-based applications to facilitate the advice exchange between patients and physicians. Furthermore, we plan to visualize the developed application in the virtual reality.

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Appendix A:

Survey the Physical Activity Level of Adults

Nowadays, physical inactivity (lack of physical activity) has been ranked the fourth in the list of leading risk factors for global mortality since it causes 6% of deaths globally according to a recent report of World Health Organization. Thus, there is an urgent need to motivate people to increase their physical activity level in order to promote their activity level as well as reduce the risk of diseases related to the physical activity level such as heart diseases. One possible solution is motivating them by recommending the least period of daily physical activity (30 min. of regular physical activity according to American Heart Association) that guarantees wellbeing taking into account user's current situation and surrounding environment's conditions (user context).

So, we designed this questionnaire in order to evaluate physical activity level of participants (random sample). Also, we aim to determine the impact of users' context on their physical activity level in addition to determine users' willingness to attach sensors such as accelerometer to their bodies to track their physical activity.

Kindly answer the following questions which won't take more than 5 min. We really appreciate your collaboration and thanks in advance.

* Required

Personal Information: Please specify your gender *

- ○ Male
- ◉ Female

Personal Information: Please specify your age group *

- ○ Less than 20
- ○ 20 - 29
- ○ 30 - 39
- ○ 40 - 49
- ○ 50 - 59
- ○ 60 and above

For how long do you exercise daily? *

- Less than 15 min.
- 15 min. - 30 min.
- 30 min. - 60 min.
- 60 min. - 90 min.
- More than 90 min.
- I don't exercise

In your opinion, which of the following affects your physical activity level negatively? *

- Weather Conditions
- Location
- Work environment
- Your work commitments (appointments and deadlines)
- Your mode
- Your weight
- Your health conditions
- All of them
- None of the above
- Other:

Do you agree to attach a sensor to your body such as accelerometer or ECG in order to specify your energy consumption? *

- Yes
- No
- NA

Do you perform the minimum amount (30 min.) of physical activity recommended daily? *

For example: walking, biking, running, etc.

- Yes
- No

Appendix B: Post-Experiment Questionnaire

Dear Participant,
First of all, thank you for your collaboration. Kindly answer the following questions as a follow up after following system advice.
Thank in advance,
Hawazin

* Required

Does following the provided advice by the system help you to be more active *
Please chose the appropriate scale

- Yes
- No
- Neutral

Q2. Evaluate the impact of the system on your physical activity level
It made me:

- Very active
- Active
- Less active
- Not active

Q3. Does knowing the amount of calories that you need to burn daily make sense for you? *

- Yes
- No
- Neutral

Does knowing the amount of calories that you need to burn daily motivate you to follow the provided advices?

- Yes
- No
- Neutral

Are location and weather in the provided advice encouraged you to follow the advice?

- Yes

○ No

○ Neutral

How do you evaluate your overall experience of using the proposed system?

○ Excellent

○ Very Good

○ Good

○ Acceptable

○ Poor

Finally, do you have any suggestions or comments in order to improve the system?

We really appreciate your valuable comments!