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MOPET: A context-aware and user-adaptive wearable system for fitness training

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Summary

Objective: Cardiovascular disease, obesity, and lack of physical fitness are increasingly common and negatively affect people's health, requiring medical assistance and decreasing people's wellness and productivity. In the last years, researchers as well as companies have been increasingly investigating wearable devices for fitness applications with the aim of improving user's health, in terms of cardiovascular benefits, loss of weight or muscle strength. Dedicated GPS devices, accelerometers, step counters and heart rate monitors are already commercially available, but they are usually very limited in terms of user interaction and artificial intelligence capabilities. This significantly limits the training and motivation support provided by current systems, making them poorly suited for untrained people who are more interested in fitness for health rather than competitive purposes. To better train and motivate users, we propose the mobile personal trainer (MOPET) system.
Methods and material: MOPET is a wearable system that supervises a physical fitness activity based on alternating jogging and fitness exercises in outdoor environments. By exploiting real-time data coming from sensors, knowledge elicited from a sport physiologist and a professional trainer, and a user model that is built and periodically updated through a guided autotest, MOPET can provide motivation as well as safety and health advice, adapted to the user and the context. To better interact with the user, MOPET also displays a 3D embodied agent that speaks, suggests stretching or strengthening exercises according to user's current condition, and demonstrates how to correctly perform exercises with interactive 3D animations.
Results and conclusion: By describing MOPET, we show how context-aware and user-adaptive techniques can be applied to the fitness domain. In particular, we describe how such techniques can be exploited to train, motivate, and supervise users in a wearable personal training system for outdoor fitness activity.

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1. Introduction

Cardiovascular disease, obesity, and lack of physical fitness are increasingly common and negatively affect people's health, requiring medical assistance and decreasing people's wellness and productivity. These problems can be prevented or alleviated by regularly practicing physical activities and sports, but a lot of people are not motivated enough or get involved in physical activities rarely, wrongly or irregularly, wasting potential benefits and even risking injuries.

Information technology researchers as well as companies are devoting an increasing attention to sports, fitness and physical activities to support people with new devices and applications at home [1,2] and outdoors [3–9]. In particular, wearable solutions are very promising because they can assist the user anywhere and allow her to get the benefits of open-air environments, such as clean air and sunlight. However, user interfaces of current commercial products as well as their artificial intelligence capabilities are extremely limited. Moreover, current products do not focus much on user's motivation and training: most solutions are based on a digital watch interface and measure or derive user's parameters without trying to recognize interesting patterns and provide more sophisticated user-adaptive and context-aware advice.

To overcome the above mentioned limitations and provide users with personalized training and motivation support, this paper proposes the MOPET system, a wearable system that supervises a physical fitness activity based on alternating jogging and fitness exercises in open-air environments. MOPET provides motivation as well as safety and health advice, adapted to the user and the context, by exploiting real-time data coming from sensors, knowledge elicited from a sport physiologist and a professional trainer, and a user model that is built and periodically updated through a guided autotest. To improve user interaction, MOPET also displays a 3D embodied agent that speaks, suggests stretching or strengthening exercises according to user's current condition, and demonstrates how to correctly perform the chosen exercises with interactive 3D animations.

MOPET is designed to be used anywhere the user can run or walk outdoors. The user wears an heart rate monitor with a 3D accelerometer around her chest, and a PDA with a built-in GPS unit on her wrist. User's parameters such as heart rate, position and exercising time are analyzed and visualized. The first time the user runs MOPET, the embodied agent asks for user's gender, age, weight and height, then it invites the user to perform an autotest: a particular exercise which consists in walking onto and off a step, as demonstrated by the embodied agent with a 3D animation. By considering the information provided by the user and her heart rate during the autotest, MOPET builds an initial user model. Based on the user model and the information acquired or derived from the sensors, MOPET suggests to increase or reduce jogging speed, provides advice and proposes different types of exercises, which are demonstrated with interactive 3D animations.

The paper is organized as follows. Section 2 surveys related work on computer-aided physical exercise, especially focusing on mobile and wearable solutions. Section 3 summarizes our previous work on a preliminary prototype of MOPET [10]. Section 4 analyzes in detail how we extended that preliminary prototype with context-awareness and user-adaptation capabilities. Section 5 provides conclusions and outlines future research directions.

2. Related work

2.1. Indoor applications based on embodied agents

Philips Virtual Coach [1] was one of the first projects to employ an embodied agent which acts as a personal trainer to motivate the user. The system is meant to be used at home with a stationary exercise bike. A 2D embodied agent is projected on a screen, which also shows a virtual environment representing an open-air landscape. With a study on 24 users, the authors showed that the embodied agent lowered perceived pressure and tension, while the virtual environment offered fun and had a beneficial effect on motivation. However, the embodied agent was not as effective as authors expected, but this may be due to the information provided by the agent rather than the agent itself. Indeed, the system provides the user only with information about her heart rate, instead of motivating her by reporting the calories she burnt or speaking about other benefits of physical activity.

EyeToy: Kinetic [2] is an indoor fitness training system for the Playstation 2 and exploits an EyeToy camera, i.e. a cheap webcam-like device, which detects user's movements. The application allows the user to choose between a male or female personal trainer and creates an individual 12-week plan, taking into account user's height, weight, age, familiarity with EyeToy games and physical condition (by means of a short questionnaire). The application adopts a game style, presenting martial arts, Tai Chi and cardio exercises as entertainment. During the games, user position is monitored to determine her score and give her suggestions on how to perform the exercise better. The personal trainer is a 3D embodied agent that comments on the game, daily, weekly and monthly performance giving the user an "E" to "A+" mark and congratulating her for the results or encouraging her to keep training and further improve. However, since EyeToy: Kinetic uses a single simple camera, it can detect only movements on a 2D plane, severely limiting the actions users can do. Moreover, since it does not consider heart rate, it cannot detect if the user is exercising at the correct intensity.

2.2. Wearable applications

The two solutions described in the previous section are both meant for indoor use. Therefore, they do not allow one to get the benefits of exercising in outdoor natural environments. To support people in open-air physical activities, some researchers [3,8,9] and companies [4—7] proposed wearable sensors, such as heart rate monitors and pedometers, and mobile applications for notebooks, PDAs and smartphones.

To monitor user's physiological parameters (e.g., heart rate and temperature) during physical activities, Knight et al. [3] proposed the SensVest, a wearable device integrated in a shirt that can measure user's heart rate, body temperature and acceleration and send them to a remote computer. This device focuses on sensing aspects and does not come with analysis or training applications that could run on a mobile device.

Polar heart rate monitors [4] are commercial wearable devices that consist in a wrist-worn watch unit and a chest-worn heart rate sensor. Besides measuring heart rate and deriving other parameters, such as burnt calories, Polar devices can give basic motivational feedback, such as "calorie bullets", i.e. beeps that occur every time a certain amount of calories is burnt, inciting the user to keep running and burn other calories. After a training session, some Polar devices allow the user to transfer her data to a PC or to send them to a Polar web site for further analysis. One device is able to send data via infrared to Nokia 5140 phones provided with a Java application that allows the user to plan and keep track of her physical activities. However, since heart rate data can be sent only after the user has completed the training session, real-time data analysis is not possible.

Nike+ iPod Sport Kit [5] consists in a pedometer that fits into special Nike shoes and in a receiver that is connected to iPods. The iPod can be worn using special Nike T-shirts and the personal training software can provide information on distance and speed while listening to music. Since it relies on steps and elapsed time, the system can incite the user in running for a distance or a period that can fit a plan based upon her goals and her previous performance, while monitoring of physiological parameters is not supported.

Unlike the previously discussed systems, Suunto t4 [6] provides a function (Coach) that monitors and makes suggestions about adjustments in user's workout routine. It follows the American College of Sports Medicine [11] guidelines to plan the optimal intensity and duration of the next workout, adapting planned exercise length to user's performance and maintaining an up-to-date plan. If user's workout exertion is above or below the optimal level, the system adjusts the suggested intensity and duration of the next workout to compensate for the difference. The device provides information about heart rate, burnt calories, speed and distance, along with an estimation on how the workout improves user's aerobic fitness, but, unfortunately, this information is only displayed with numbers, text and bar charts on a watch-like unit.

Mobile graphical analysis of user's parameters, along with training plans and 2D illustration of exercises are supported by VidaOne MySportTraining software for PDAs [7]. The software can acquire data in real-time from a GPS, but unfortunately heart rate data can be acquired only via infrared after the training session. Therefore, advice and motivation during the physical activity cannot be provided.

Oliver and Flores-Mangas [8] proposed MPTrain, a smartphone-based trainer that analyzes heart rate and acceleration data to select and change one's favorite music. By choosing music with a specific rhythm, MPTrain encourages the user to speed up, slow down or keep the pace according to her training goals.

Personal wellness coach [9] is another system that tracks user's movement, monitors heart rate, and provides music feedback. This wearable system can send the data produced by an heart rate monitor, an accelerometer and a body temperature sensor to a laptop that can be up to 9 m away. Beside providing music feedback, the system can warn of overexertion and motivate the user with interactive audio. Anyway, the need for a laptop limits the wearability of personal wellness coach. As a result, mobile physical activities, such as outdoor running and exercising on fitness trails become impractical.

3. Preliminary prototype of MOPET

A preliminary simple prototype of MOPET we developed at the beginning of our project was based on a

Figure 1 The embodied agent is demonstrating a typical exercise with rings on a fitness trail.

PocketPC connected to a GPS device and was meant to guide users in fitness trails, i.e. trails where the user has to alternate jogging and exercising. The user runs along an indicated path and has to stop when she arrives at exercise stations. In each exercise station, the user finds an exercise tool to perform a specific fitness exercise. The prototype includes an embodied agent (Fig. 1) and helps users in three ways:

- *Navigation*: location-aware audio and visual navigation instructions are provided to allow the user to follow the correct path in the fitness trail.
- *Motivation*: audio and visual feedback on user's speed is provided. This is meant to motivate the user to maintain an adequate speed during the entire session.
- *Training*: when the user reaches an exercise station, the embodied agent is animated in 3D to show how to correctly perform the exercise.

As an alternative to the embodied agent, one could display videos of a real trainer performing the exercises on the mobile device, but using 3D animations has two main advantages over pre-recorded videos: (i) 3D animations can be interactively explored by the user, who can easily watch the exercise from the desired positions to clarify her doubts, and (ii) animations require much less space than videos on the mobile device.

3.1. Navigation

MOPET displays a location-aware map of the trail on the screen of the PDA. User position on the map is marked with an icon depicting a running person. Other icons are used to mark checkpoints: the start—finish (a chequered flag), the fitness trail exercise stations (a person performing an exercise), the points where the trail forks (a compass) and additional points where MOPET tells the user her speed (a red triangular flag). Moreover, the trail is marked with a polygonal line which is initially blue. MOPET provides common navigational cues, such as changing the user's position in the map based on GPS data and changing the color of the polygonal lines to indicate the completed parts of the trail. Fig. 2 shows the map after the user has completed the left half of the trail. However, this graphical feedback can be conveniently examined only by a user who is not running, so we provide the user also with audio information: when she approaches a fork, MOPET gives her vocal directions using the internal speaker of the PDA or a Bluetooth earphone.

Figure 2 Map with the left half of the trail completed.

3.2. Motivating the user

MOPET motivates the user, by exploiting graphics as well as audio. The application calculates average user's speed on the different parts of the trail. We divided speed into four ranges: slow walking (<5 km/h), fast walking (5—8 km/h), moderate running (8—12 km/h) and fast running (>12 km/h). To provide the user with immediate audio feedback, MOPET tells the user her current speed and incites her to increase or decrease her speed, as soon as a checkpoint is reached. For each speed range, different pre-recorded sentences are available. Sentences are not aggressive and try to highlight positive aspects of user's performance, even if she walks very slowly (e.g., "You are walking at a regular pace. If you are not tired, try to increase your speed."). We chose to incite users gently because the evaluation results of [1], which incites aggressively (e.g., "Your heart rate is slow! Run faster!"), were not as positive as expected. The user can also get visual feedback about her speed during the entire session by checking the color of the lines corresponding to the different parts of the trail, since they map speed into a blue—red temperature scale.

3.3. Training

In fitness trails, exercises are usually explained by graphic plates in the stations (see Fig. 3 for an example). These plates are often difficult to understand and exercises could thus be performed improperly, wasting the benefits of the physical activity and also risking injuries.

Figure 3 Graphic plate of a fitness trail exercise.

Therefore, MOPET gives location-aware exercise demonstrations and explanations on how to perform the exercises correctly and safely: as the user approaches a fitness trail exercise station, the embodied agent first whistles to attract user's attention and invites the user to look at the PDA display, then it demonstrates how to correctly perform the exercise with a 3D animation (for example, Fig. 1 refers to the demonstration of an exercise with rings).

We evaluated navigation, motivation and training support provided by MOPET on 12 users. GPS logs, questionnaires and videos of users' performance were analyzed, showing that MOPET is more useful than fitness trail maps for helping users to orient themselves in a fitness trail. MOPET is also much more effective than metal plates for learning how to correctly perform exercises. The mean of users' ratings for motivation support was 3.33 on a five-value Likert scale. This was partly due to the very limited personalization capabilities of the training system due to the absence of a user model (e.g., we used general values for speed thresholds, without considering the particular user's weight, age and so forth) and to context-awareness relying only on GPS data. The evaluation of the first prototype of MOPET is described in detail in [10].

4. The new MOPET: context-awareness and user-adaptation extensions

Starting from the analysis of the limitations of the first prototype of MOPET and the suggestions provided by the users, we extended the system in different directions, focusing on artificial intelligence, context-awareness and user-adaptation aspects to provide a more effective motivation support as well as safety and health advice.

MOPET now offers three new personalized functionalities:

- it guides the user through the autotest described in Section 1, also suggesting how frequently she should walk onto and off the step;
- it supports jogging from a fitness exercise to another, by (i) visualizing information on speed and heart rate, (ii) providing motivational and safety advice, and (iii) suggesting appropriate exercises for those situations where the user is not in a fitness trail with exercise stations;
- it provides advice while the user performs an exercise.

To acquire more information about the user, we added the support for a new wireless sensor, i.e. an heart rate monitor with a 3D accelerometer. Fig. 4 shows the devices worn by the user: the heart rate monitor with the 3D accelerometer is worn on the user's chest, the PDA is worn using a wristband and gets position data through an integrated Sirf Star III GPS.

As a result, MOPET can now acquire or derive the following information, which constitutes the sensed context:

- cinematic information, i.e. user's position, 3D acceleration and speed;
- physiological information, i.e. ECG, heart rate and burnt calories;
- time elapsed from the beginning of the training session or since the user started to perform an exercise.

Besides analyzing the sensed context, MOPET relies on a user model, which consists of:

- personal information, i.e. weight, height, gender and age, which is provided by the user before starting the autotest;
- physiological information, i.e. the maximum volume of oxygen the user can consume in a minute, which is calculated with the autotest;
- user's experience with each strengthening exercise, i.e. how many times the user completed the exercise keeping her heart rate under the required threshold, how many times she completed the exercise with an higher heart rate, and how many times she quit the exercise instead of completing it.

Figure 4 Wearing MOPET during outdoor activities.

The high-level architecture of MOPET is illustrated in Fig. 5 and is organized into three main subsystems:

- The context analyzer acquires raw data from the sensors and analyzes it to derive additional information, such as burnt calories and speed, by considering also information about the user (e.g., weight), available from the user model database. Collected and derived information about the sensed context is then provided to the user interface subsystem and to the training expert subsystem. At present, the context analyzer considers GPS and heart rate data, while it simply logs acceleration data for future off-line analysis.
- The user interface visualizes speed and heart rate graphs, the total amount of calories burnt in the current training session, and the time elapsed since the user has started running. Moreover, whenever the training expert subsystem decides that advice, suggestions or 3D demonstrations are needed, the user interface retrieves the appropriate media from the media database and plays audio or 3D animations to the user.
- The training expert considers both the information provided by the context analyzer and the information in the user model database, and applies the rules stored in the knowledge base (KB) to decide if (and which) advice is needed. Considering the functionality chosen by the user, which is provided to the training expert by the user interface, the training expert activates one of its three modules: user autotest, jogging, or exercise. The user autotest module, besides deciding if advice or motivation are needed during the autotest, is responsible for updating the user model database with the information it calculates during the autotest.

The three subsystems are described in detail in the following subsections.

4.1. Context analyzer

While the user is jogging between exercises, the context analyzer considers her positions in a given time interval (currently set to 5 s) and calculates derived information, i.e. mean speed and calories burnt during the considered interval. While GPS data is usually accurate enough for measuring user's speed, it occasionally contains highly inaccurate positions that should not be used to calculate user's speed. Therefore, the context analyzer tries to detect and discard such inaccurate positions by calculating mean speed in each time interval as follows:

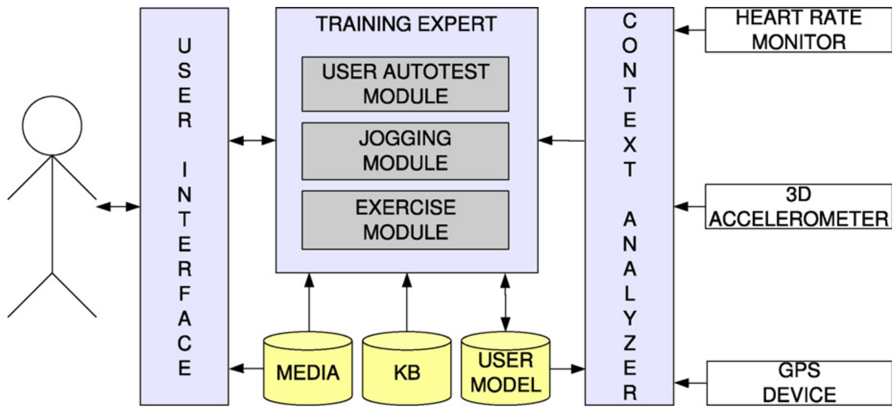

Figure 5 MOPET architecture.

1. it calculates instantaneous speeds by considering single pairs of subsequent GPS positions;
2. if the instantaneous speed value for a particular pair of positions is physically feasible for a jogger, then the instantaneous speed is considered reliable, otherwise it is discarded;
3. it calculates the mean speed in the time interval by considering only the reliable values; if there are no reliable values in the time interval, the mean speed of the previous time interval is used.

Once the context analyzer has calculated user's speed in a time interval, it estimates the user's energy expenditure (J) in the same interval by using the following formula:

$$\text{EnergyExpenditure} = \text{Speed} \times \text{Weight} \times \text{Time} \times \text{EC}$$

where Speed is the average speed in m/s in the time interval, Weight the user's weight in kilograms retrieved from the user model (current weight is periodically provided or confirmed by the user before taking the autotest), Time the duration of the time interval in seconds, and EC is the energetic cost of jogging. This last variable is expressed in joules per kilogram and per meter. Users who had their jogging energetic cost measured in a physiology laboratory can enter it during the autotest, otherwise EC is set at 3.8, i.e. an average value for joggers on flat ground.

While the joule is the standard unit for measuring energy in the International System (SI), it is better to provide the user with energy expenditure in calories, since people commonly use this unit. Therefore, the context analyzer converts the energy expenditure in calories before sending it to the other subsystems.

Considering heart rate, the employed sensor provides only electrocardiographic (ECG) data. This data can be visualized as an electrocardiogram, which might be interesting for physiologists and cardiologists, but it is not familiar to the intended users of MOPET. Therefore, the context analyzer analyzes ECG data and counts the local maximums in a time interval. Since ECG data has two local maximums for each heartbeat, the analysis derives the number of heartbeats per minute (bpm), i.e. user's heart rate.

4.2. User interface

In designing the MOPET interface, we had to deal with many challenging constraints and requirements. Mobile devices have several limitations in terms of performance, input peripherals and display [12], and user's activities such as jogging or exercising further limit the attention the user can devote to the interface.

We designed an interface that can be navigated by using only the two softkeys and the arrow pad of the PDA. The user is asked to use the pen and the virtual keyboard only to enter her personal information before the autotest, but the autotest is not needed in each training session and, after the first time, the user rarely needs to change her personal information. To further simplify user interaction with MOPET, the user interface can automatically switch screens, e.g., after the end of an exercise or after the autotest, the user interface returns to the screen which provides information about the jogging activity.

To provide suggestions, advice and accurate demonstrations of the exercises, we use a 3D embodied agent, as mentioned in the previous sections. The agent follows the ISO H-Anim specifications [13], which standardize joints and segments of virtual human bodies. More specifically, it is compliant with level of articulation 2 of H-Anim: it can thus move 71 joints, displaying the correct position of all body parts, including fingers. Moreover, an

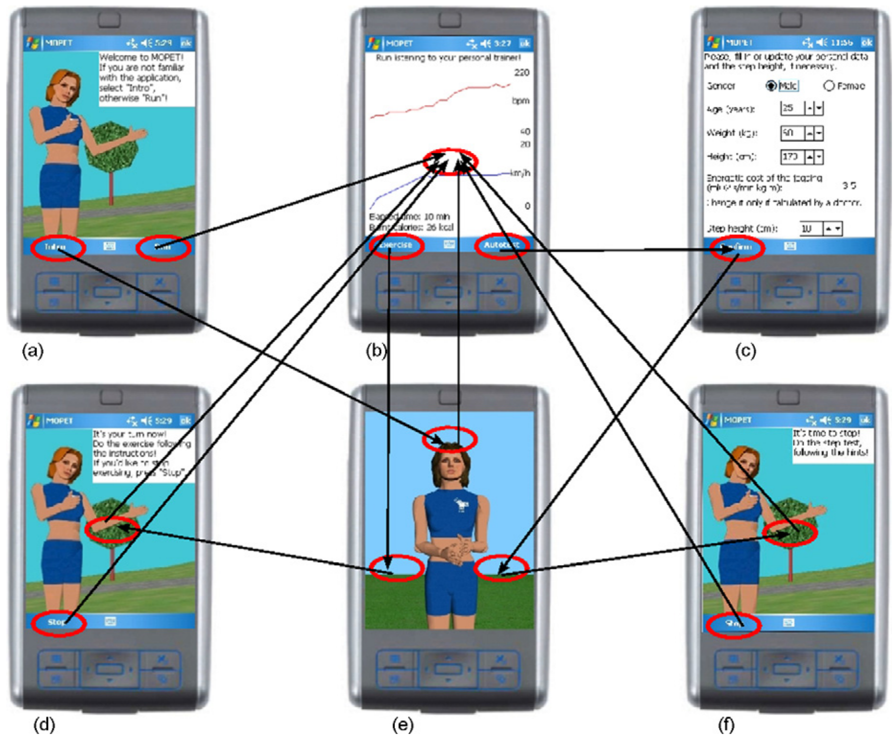

Figure 6 The different screens of the user interface: (a) welcome screen, (b) jogging screen, (c) personal information screen, (d) exercise screen, (e) 3D screen and (f) autotest screen. Arrows indicate possible switches among screens. Arrows starting from buttons represent switches triggered by the user, the other arrows represent switches triggered by the system.

embodied agent which can move and speak may attract users' attention and convey conversational and emotional cues [14,15], which is useful for an effective users' motivation. To model animations of 3D embodied agents and display them on mobile devices, we created a specific software called MAge-AniM [16].

Fig. 6 illustrates the different screens of the user interface and the possible switches among screens: when the user starts MOPET, a welcome message is displayed (Fig. 6a); the user can press one of the two softkeys to watch an introductory 3D animation about system functionalities (Fig. 6e) or immediately get information about burnt calories and elapsed time along with speed and heart rate graphs about the last minute of activity in the jogging screen (Fig. 6b). If the user chooses to watch the introductory 3D animation, the jogging screen is automatically displayed at the end of the introduction.

In the jogging screen, the two softkeys allow the user to start a fitness exercise or the autotest. In the first case, the user interface asks the training expert subsystem to choose an exercise that is appropriate for the user and the sensed context (see Section 4.3.3); then it provides the user with an interactive 3D animation of the embodied agent that demonstrates how to perform the exercise correctly and safely. To view the correct movements under different viewpoints, the user can use the navigation pad: left and right keys rotate the embodied agent, while up and down keys get closer or farther from it. At the end of the demonstration, the user interface displays a message which invites the user to start the exercise (Fig. 6d). During the exercise, the user interface plays voice messages which provide information on how many times the exercise should be repeated and suggest a correct rhythm.

If the user chooses the autotest, the user interface plays a voice message which introduces the autotest exercise, then it displays a form (Fig. 6c) to collect or update user's personal information (i.e. gender, age, height and weight) and the height of the step that will be used for the test. After the user completes the form, the information is sent to the training expert, and then the embodied agent demonstrating how to perform the test is displayed. After the 3D animation, the user is invited to perform the test herself (Fig. 6f) following the suggestions and the advice of the training expert (see Section 4.3.1). At the end of the autotest, the interface provides the user with the results of the test, then it switches to the jogging screen.

4.3. Training expert

The training expert takes decisions by considering the sensed context, the information stored in the user model database, and the functionality required by the user through the user interface.

As shown in Fig. 5, the training expert is organized into three modules (user autotest, jogging, and exercise) which are respectively devoted to the user autotest, the jogging activity and the physical exercises. In the following, we examine each of them in detail.

4.3.1. The user autotest module

The autotest allows to estimate the maximum volume of oxygen (VO_2Max) the user can consume in 1 min. The User Autotest module exploits known physiological equations which involve user's heart rate (HeartRate), the power produced by the user during the exercise (Power), and some coefficients which vary with user's gender and age. HeartRate and Power have to be managed carefully, since they can vary during the exercise. Moreover, to obtain a valid estimation of VO_2Max, HeartRate should be nearly constant for some minutes and it should be inside a particular range.

Therefore, we use a context-aware strategy to determine the power which keeps user's heart rate inside the range required by the autotest. Power can be calculated by using well-known physics equations. In particular, for the autotest with the step:

$$\text{Power} = \frac{\text{Weight} \times g \times \text{StepHeight}}{\text{TimePerStep}}$$

where Weight is the user's weight, g the gravity acceleration, StepHeight the height of the step, and TimePerStep is the time required to walk onto or off the step. Since Weight, g and StepHeight are constants, the user autotest module should try different values of TimePerStep until user's heart rate is inside the required range. The idea is to start with a TimePerStep value calculated for a safe value of Power and then increase or decrease TimePerStep by considering the difference between current heart rate and the needed one. TimePerStep values are sent to the user interface, which plays a voice message saying "Up!" or "Down!" every TimePerStep seconds to pace the exercise intensity.

As a result, considering the same step with a given height, an overweight user may have an high heart rate even if incited to walk onto and off the step at a slow pace and thus TimePerStep will be kept at the initial value or will be increased, a slim but unfit user may have an heart rate in the required range with the initial TimePerStep value or after a small decrease, and a competitive athlete may require the user autotest module to significantly decrease TimePerStep.

After user's heart rate has been in the required range for 4 min, the user autotest module calculates user's VO_2Max and updates the user model database with this value and the last Power value, which will be used to calculate the initial TimePerStep for the next time the user will perform the autotest. Taking the autotest regularly allows the user to learn if VO_2Max and Power values have improved with training and thus she has achieved a better fitness condition.

4.3.2. The jogging module

The advice provided by the jogging module while the user is jogging between exercises falls in three different categories: excessive heart rate alerts, speed/intensity advice, and exercise and autotest suggestions.

Alerts and speed/intensity advice are based on user's gender, age, and heart rate, since different users can jog at the same speed, but with different effort. Moreover, a proper stretching or muscle strengthening exercise can be proposed when the user actually needs to perform that exercise, even if the user is not in a fitness trails with exercise stations. In the following, we consider the more complex case where the user is in an area without exercise stations.

The jogging module provides an excessive heart rate alert everytime user's heart rate is over critical thresholds. The higher is the unrecommended heart rate, the more frequently the jogging module will trigger alerts: for example, if user's heart rate is over the 95% of her maximum, then the jogging module will trigger an alert every 15 s, while if user's heart rate is at 85% of her maximum, an alert will be triggered every minute. The alert invites the user to slow down and sometimes tells her about the benefits of exercising often and longer rather than more intensely. Moreover, if user's heart rate keeps being higher than recommended for a given amount of time, the jogging module decides also to propose a stretching exercise which lets user's heart rate return to a safe number of beats per minute. The user can ignore the suggestion, which will be periodically proposed again if the heart rate is still excessive. If user's heart rate is not excessive, the jogging module will instead periodically suggest exercises to improve muscle strength.

Since user's maximum heart rate varies with her age, it is adapted to the specific user. Indeed, the same heart rate value (e.g., 160 bpm) can be over a critical percentage of user's maximum heart rate if the user is old, while it can be safe for a young user.

Therefore, for the same sensed context, the jogging module may suggest a strengthening exercise to a young user, but it may suggest a stretching exercise to an older one.

The jogging module also periodically proposes to perform the autotest. Finally, it can give suggestions about the jogging speed if the user walks or jogs so slowly that her heart rate is under a particular percentage of her maximum. In this case, the jogging module decides to motivate the user and thus asks the user interface to play a voice message, which the interface selects randomly from a set of alternatives. The lower the user's heart rate, the more frequently the jogging module will incite her to jog faster.

4.3.3. The exercise module

As mentioned in the previous subsection, the jogging module can suggest stretching and strengthening exercises. The user can accept the suggestion (or ask for an exercise at any moment) by selecting "Exercise" in the jogging screen. When the user is going to perform an exercise, the exercise module can adapt it to both the sensed context and the user.

Since stretching exercises are useful to let the heart rate return to a normal level, the exercise module incites the user to keep with the stretching exercise, until her heart rate is below the required threshold. The user can ignore the exercise module and quit the exercise by pressing a softkey.

Considering strengthening exercises, exercising until the heart rate goes below or above given thresholds is not suitable, since these exercises are not meant for decreasing the heart rate and a regular exercise is better than short intense activities, in particular for prevention of cardiovascular disease. Therefore, the approach we propose considers not only user's heart rate, but also her experience with the exercise: for each strengthening exercise, we define different levels, starting from a very easy level to one that can be good also for competitive athletes. The first time the user tries an exercise, she exercises at the first level and thus the exercise module proposes a safe amount of repetitions at a safe pace. At the end of a given exercise, the exercise module updates user's experience with the exercise in the user model database, by increasing the number of times the user completed the exercise keeping her heart rate below the required threshold, the number of times she completed the exercise above the threshold, or the number of times she quit the exercise instead of completing it.

When the number of times the user completed the exercise keeping her heart rate under the required threshold reaches given values, the user advances to the next level of that exercise, which requires more repetitions or a faster pace.

The exercise module thus chooses the level of an exercise in a user-adaptive (considering user's experience with the exercise) as well as context-aware way (for the same user, the same exercise and the same level, user's experience with the exercise is updated differently based on the different user's heart rates during the exercise).

5. Conclusions and future work

This paper proposed MOPET, a wearable personal training system which supports user's outdoor fitness activities with context-aware and user-adaptive advice, based on sensed context, a user model, and knowledge elicited from a personal trainer and a sport physiologist.

Our research is now proceeding in several directions. We will introduce further adaptation capabilities by allowing the user to state more specifically her goals (e.g., weight loss, cardiovascular training, and muscle strength) so that MOPET can create and keep updated a training program that is suited to user's goals. We will also integrate an exercise recommendation system that takes into account users' ratings of the performed exercises. An interesting issue will be then to find a strategy for balancing what the user likes and what the user needs.

Moreover, we are proposing visualizations for the off-line analysis of large sets of data collected by MOPET [17] and we are working on the integration of additional wireless sensors. In particular, we have already added the support for a pulse oximeter that can be clipped onto a user's ear and provide additional physiological parameters such as oxygen saturation, which will be exploited to further tailor advice. Finally, we will study accelerations during particular fitness exercises to find possible patterns which can be exploited to check if the user performs the exercise correctly.

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