Artificial Intelligence in Medicine (2008) **42**, 153—163

ARTIFICIAL INTELLIGENCE IN MEDICINE

http://www.intl.elsevierhealth.com/journals/aiim

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

Fabio Buttussi, Luca Chittaro *

HCI Lab, Department of Mathematics and Computer Science, University of Udine, Via delle Scienze 206, 33100 Udine, Italy

Received 20 November 2006; received in revised form 13 November 2007; accepted 21 November 2007

KEYWORDS
Wearable systems;
Context-awareness;
User-adaptation;
Fitness training;
Embodied agents

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.

* Corresponding author. Tel.: +39 0432 558450; fax: +39 0432 558450.
E-mail addresses: fabio.buttussi@dimi.uniud.it (F. Buttussi), luca.chittaro@dimi.uniud.it (L. Chittaro).

0933-3657/$ — see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.artmed.2007.11.004

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

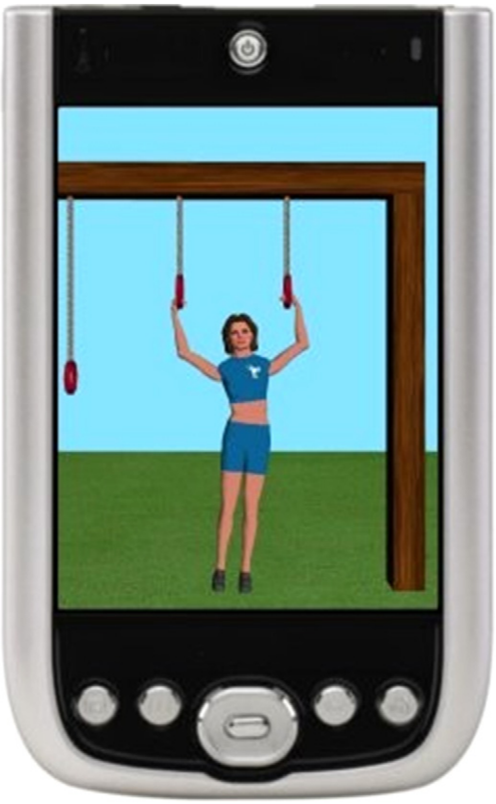

Figure 1 The embodied agent is demonstrating a typical exercise with rings on a fitness trail.

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.

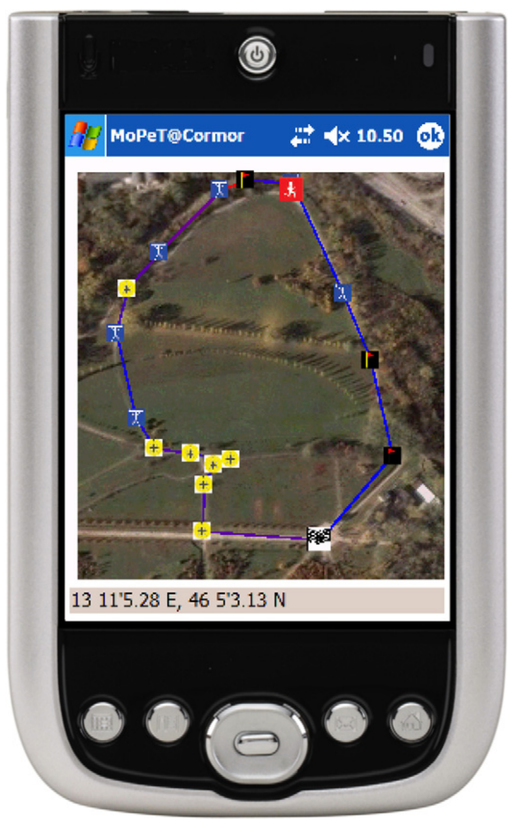

Figure 2 Map with the left half of the trail completed.

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.

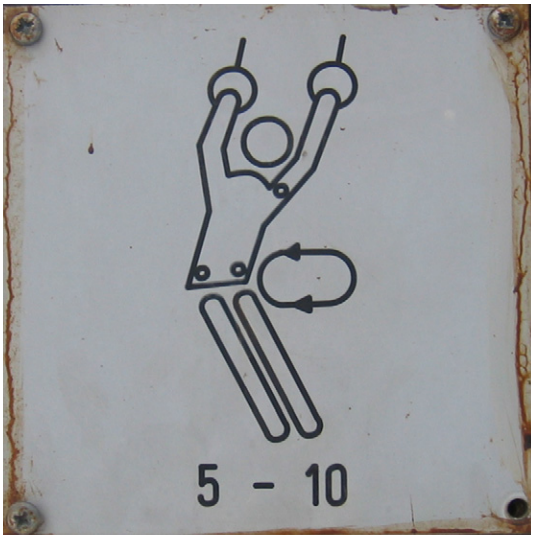

Figure 3 Graphic plate of a fitness trail exercise.

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.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.