Adaptation of graphics and gameplay in fitness games by exploiting motion and physiological sensors

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Abstract. Obesity and lack of physical fitness are increasingly common in adults as well as children and can negatively affect health. Regular physical activity, such as jogging or training in a fitness center, is recommended by physiologists to fight obesity and improve one's fitness, but usually requires considerable motivation. Recently, researchers as well as companies have proposed a few *fitness games*, i.e. videogames where users play by performing physical exercises, in which game elements (such as graphics and gameplay) are used to encourage people to exercise regularly. This paper proposes a fitness game system which aims at combining arcade-style game graphics, physiological sensors (e.g. heart rate monitor, 3D accelerometer), and an adaptation engine. The adaptation engine considers personal information provided by the user (e.g., age and gender), her current heart rate and movements, and information collected during previous game sessions to adjust the required intensity of physical exercises through context-aware and user-adaptive dynamic adaptations of graphics and gameplay. Besides describing the general system, the paper presents two implemented games and a preliminary user evaluation, which also led us to introduce in the system a 3D virtual human.

Key words: Fitness games, user-adaptive systems, context-awareness, physiological parameters

1 Introduction

Obesity and lack of physical fitness due to inappropriate eating habits and insufficient physical activity are increasingly common in adults as well as children. This is detrimental to people's wellness and productivity, can negatively affect health, and increase the need for medical assistance. Regular physical activity, such as jogging or training in a fitness center, is recommended by physiologists to fight obesity and improve one's fitness, but usually requires considerable motivation. Since videogames are attractive and may easily engage people (especially youngsters), a solution recently proposed by some researchers (e.g., [1, 2, 5, 6]) and companies (e.g., [7]) consists in videogames that users play by performing physical exercises. While some of these videogames (e.g., [1, 2]) are entertainment systems that may have a positive effect on users' fitness, others (e.g., [5, 7]) have been specifically thought as fitness applications and are called *fitness games*.

While the idea of providing motivation to perform physical activity by exploiting videogame elements (such as attractive graphics and gameplay) has shown to be promising [1, 2], there is still the risk that the user will exercise irregularly or in a wrong way (e.g., because she does not performs the right movements or she exercises at too high intensity), thus wasting potential benefits and even risking injuries. To ensure that the user will exercise at the right intensity, Masuko and Hoshino [5] have recently proposed to continuously monitor the heart rate of the user and use the measured value to dynamically adjust the behavior of the game.

In this paper, we extend Masuko and Hoshino's idea, and propose a fitness game system which aims at combining the attractive graphics and gameplay of arcade games, physiological and motion sensors, and an adaptation engine. In our system, the user provides input to arcade-style videogames by performing physical exercises which were recommended by a sport physiologist and a professional trainer. The adaptation engine of the system considers personal information provided by the user (e.g., age and gender), information collected during previous game sessions (e.g., score), and sensor readings (to detect the user's current physiological parameters and movements) to suggest the proper exercise intensity through context-aware and user-adaptive dynamic adaptations of graphics and gameplay.

The paper is organized as follows. Section 2 surveys related work. Section 3 introduces our fitness game system by describing its architecture, sensed context, the adaptive engine, and two implemented games. Section 4 describes the results of a preliminary user evaluation. In Section 5, we describe how the evaluation led us to introduce a 3D virtual human to provide in-game movement demonstrations and advice. Section 6 concludes the paper.

2 Related work

Computer applications that support fitness activities by exploiting videogame graphics and gameplay have been explored by some research projects [1, 2, 5, 4], as well as by a few commercial products (e.g., [7]). For example, in the Shadow Boxer [2] game, user's movements control an avatar that has to hit the objects which are displayed on the screen. The user plays by performing the basic movements of fitness boxing, which are detected by a camera. Another example is Kick Ass Kung-Fu [1], a martial arts game in which the user fights against virtual opponents with punches, kicks and acrobatic moves. In this game, the video image of the user (acquired through a camera) is embedded into a 3D world projected on two screens. To add fun, the game can exaggerate user's jumps and use slow motion for players' acrobatic moves.

The potential benefits of Shadow Boxer and Kick Ass Kung-Fu on user's fitness have been investigated by carrying out evaluations, in which both games were able to significantly increase users' heart rate. For example, the evaluation of Kick Ass Kung-Fu on 46 users showed that the game could be used as a fitness activity, since the median of users' heart rate after fighting an opponent was at 90% of their maximum heart rate. However, as suggested in [5], in these games people might not exercise efficiently, since exercise intensity is not adjusted individually based on heart rate (as it is recommended also by sport physiologists). The proposed solution is to monitor the user's heart rate during the game, and adjust the game behavior so that the user exercises at the right level of intensity. This approach was experimented in a boxing-like videogame [5], where the user's arms movements were detected by a camera, and the behavior of computer-controlled opponents was dynamically adjusted so that the user could reach and maintain a target optimal heart rate.

Other fitness games and fitness applications provide a user interface based on a virtual human that motivates the user to exercise or even acts as a virtual trainer. For example, the Philips Virtual Coach [4] system employs a stationary exercise bike, heart rate sensors, and a 2D virtual coach projected on a screen, which also displays a virtual environment representing an open-air landscape. The virtual coach appears every minute to give feedback to the user, based on her heart-rate information. A study on 24 users found that the virtual coach lowered perceived pressure and tension, while the virtual environment was perceived as fun and had a beneficial effect on motivation. The application EyeToy: Kinetic [7] is an example of commercial fitness game. It exploits a webcam to capture the user's body image and visualize it on the screen together with synthetic game elements, which the user has to hit by making specific movements. The game allows the user to choose between a male or female 3D virtual trainer, and creates an individual 12-weeks training plan, taking into account user's height, weight, age, physical fitness and familiarity with EyeToy games (information is acquired through a questionnaire). During the game, the virtual trainer gives suggestions on how to correctly perform the exercises. Moreover, the virtual trainer comments on the user's performance, giving her marks and congratulations for the results or encouraging her to keep training and further improve. Finally, it is interesting to note that EyeToy: Kinetic motivates the user also by giving purely graphic rewards, e.g. it draws a shining aura around the user's image on the screen if she correctly performs the required sequences of movements.

3 A context-aware and user-adaptive fitness game system

To bring together the benefits of videogame graphics and gameplay on motivation and those of physical exercises performed at correct intensity on one's fitness, we propose a context-aware and user-adaptive fitness game system. Our approach differs from the fitness games mentioned in the previous section in the sense that we aim at mapping fitness exercises into control actions for any kind of videogame and graphical environment. Therefore, while most of the solutions proposed in the literature are restricted to specific sports games (e.g., boxing, fighting) and exercises (e.g., punches, kicks), our system has been designed to be more general, e.g. allowing us to implement a space game where the user controls the position of her spaceship by performing an exercise based on knee bends.

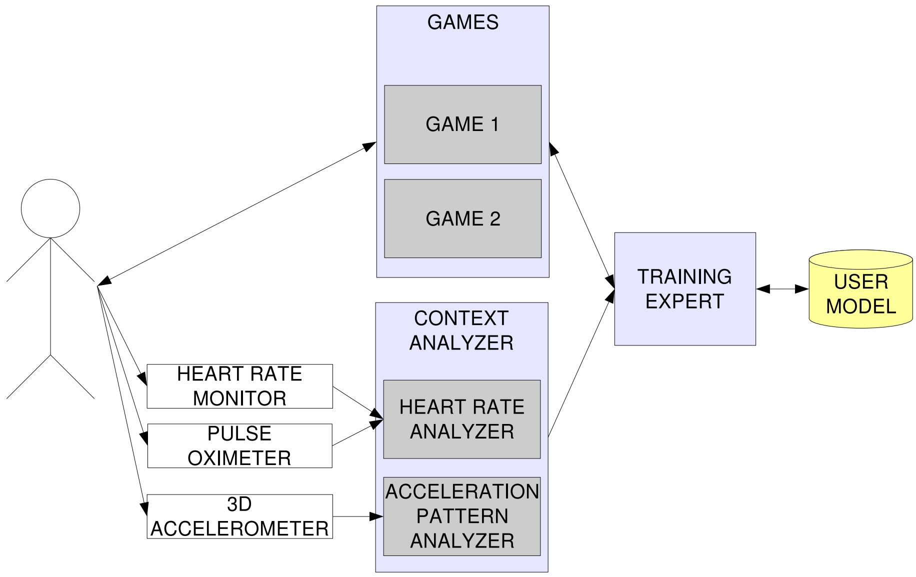

Fig. 1. The architecture of the proposed fitness game system.

The architecture of our system is illustrated in Figure 1:

– The *Context Analyzer* subsystem acquires raw data from available physiological and motion sensors and analyzes it to derive higher level information on the user's physiological state and movements. In particular, the *Heart Rate Analyzer* module processes ECG data provided by an heart rate monitor or pulse data provided by a pulse oximeter to derive the user's current heart rate. The *Acceleration Pattern Analyzer* processes acceleration data provided by 3D accelerometers and recognizes patterns that correspond to specific user's movements. The Context Analyzer then sends the derived information, such as current heart rate and user's movements, to the Adaptation Engine.
– The *User Model* database stores personal information provided by the user (i.e., nickname, age, gender, weight, height) as well as information acquired during game sessions which are related with the user's physiological state.
– The *Adaptation Engine* subsystem considers the information provided by the Context Analyzer as well as the information contained in the User Model database, and applies fitness training rules to decide if (and which) game

adaptations, such as an increase in difficulty, are needed. Moreover, it analyzes user's movements and converts them into more conventional input (e.g., up, down, fire actions) for the Games subsystem. Finally, the Adaptation Engine analyzes the personal information provided by the user as well as game events (e.g., current score) to update the User Model database.
– The *Games* subsystem provides the Adaptation Engine with a unified way to give input commands and requests for adaptations to the currently played game (possibly chosen from a set of available ones). The subsystem also handles other user's inputs (e.g., mouse events) and widgets that are reused among games (e.g., graphical representation of user's heart rate), while each particular game is implemented by a dedicated module.

All the subsystems and modules have been implemented in Java. The following subsections analyze in detail each of the three subsystems.

3.1 The Context Analyzer

In the proposed approach, the term "context" refers to all the information about the user and the environment currently acquired or derived from sensors. Each type of sensor is managed by a different module of the Context Analyzer. Current modules handle heart rate sensors and 3D accelerometer, but one could extend the Context Analyzer with additional modules that handle other types of sensors, e.g. to recognize user's movements through a camera as in some of the systems discussed in Section 2.

Considering the Heart Rate Analyzer module, we support two different wireless sensors: heart rate monitor and pulse oximeter. The considered heart rate monitor (Figure 2a) provides electrocardiographic (ECG) data, which the Heart Rate Analyzer examines to count the local maximum values in a time interval and derive user's heart rate in beats per minute. The considered sensor has some drawbacks though: it is not easy to wear, since the user has to attach two electrodes to her chest, a misplacement of the electrodes may prevent the sensor from retrieving data, and electrodes tend to detach during intensive exercise.

The pulse oximeter (Figure 2b) is clipped to the ear of the user and measures the amount of oxygen in the blood. Since the monitored signal bounces in synch with the heartbeat, the pulse oximeter can be conveniently used to acquire user's heart rate, provided that the user does not suffer from cardiovascular pathologies (in this case, the sensor provides a less accurate value). In our experience, this sensor was easier to wear, did not detach during exercises, and had the additional advantage of not requiring users to take off clothes to wear it.

To recognize some movements of the user, we employed a wireless 3D accelerometer. The 3D accelerometer is attached to a strip worn by the user and measures accelerations along the X,Y and Z axes. This sensor allows us to detect user's movements in any point within the range of the wireless network (in our case, a Bluetooth one), therefore the user has considerable freedom in choosing the preferred position where the physical exercises will be performed.

The games we implemented exploit two patterns of acceleration:

Fig. 2. Sensors currently managed by the Context Analyzer. a) heart rate monitor with integrated 3D accelerometer b) pulse oximeter.

- knee bends, characterized by variations of the acceleration along the y axis;
- left-to-right and right-to-left jumps, characterized by an acceleration along the y axis followed by accelerations along the x axis;

In our tests, the Acceleration Pattern Analyzer was able to recognize such patterns with an accuracy close to 95%. 3D acceleration data from a single accelerometer could also be exploited to recognize bends and twists of the spine by considering how gravity acceleration is distributed among the three axes: for example, when the user is standing erect, gravity acceleration is detected on the Y axis. When the user bends the spine 45 degrees to the right or to the left, half of the gravity acceleration is detected on the Y axis, and half on the X axis. More complex movements could be detected by using more accelerometers or by moving to (more expensive) motion sensors.

Finally, sensors can be combined with other game controls. For example, the heart rate monitor and 3D accelerometer in Figure 2a is equipped with an event button that we use to start the game, so that the user does not need to use the mouse or the keyboard during a game session.

3.2 The Adaptation Engine

The Adaptation Engine contains rules to:

- decide, on the basis of the user model and current context, if the user should put less or more physical effort in the game;
- consequently, during game sessions, request the Games subsystem to change graphics and gameplay to motivate the user to exercise at the optimal intensity; more specifically, each game offers three possible game modes: *keep*, to keep the user in the current heart rate range, *relax*, to reduce user's heart rate, and *exert*, to increase user's heart rate;

– at the beginning of each game session and for the chosen game, request the Games subsystem to set the difficulty level associated with each game mode; the difficulty level is a set of game specific parameters (e.g., speed of game elements, number of new opponents per minute) that ultimately determine the intensity of physical effort required to the user;
– update the user model to keep track of the relation between the performance in game sessions and the physical fitness of the user.

The user model consists of a set of personal information provided by the user on the first game session (i.e., nickname, age, gender, weight, height) and data that automatically is acquired and updated during game sessions (i.e., amount of time elapsed in each of the three above mentioned modes, maximum score reached for each game).

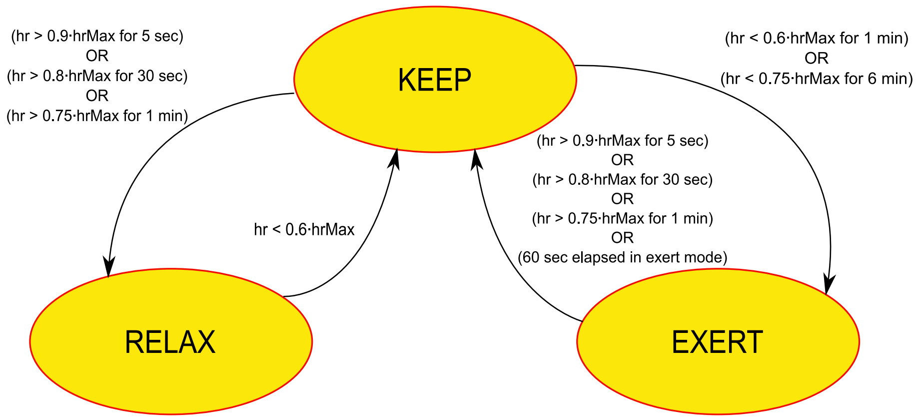

Fig. 3. Finite state automata to switch among game modes during a game session (*hrMax* is the user's maximum heart rate, determined by her age and gender).

The Adaptation Engine can prescribe within-game as well as between-games (long-term) adaptations. By considering personal information provided by the user, it can determine her maximum heart rate (*hrMax*). During interviews we carried out with a professional trainer and a sport physiologist, it was pointed out that the optimal heart rate for fitness practice is in the interval [0.6*hrMax*, 0.75*hrMax*]. Therefore, by comparing *hrMax* with the current heart rate, the Adaptation Engine can detect if the user is exercising at, below, or above the optimal intensity and thus dynamically require the Games subsystem to switch to one of the above mentioned modes. More specifically, the rules that determine transitions between modes are shown in Figure 3, where the formulas associated to the arcs were suggested by the interviewed experts.

Between-games adaptations are meant to better tailor the system to long-term changes in users' physical fitness, e.g., improvements due to regular activity with the system. More specifically, at the beginning of a game session, the Adaptation Engine considers the information collected during previous sessions, and if it detects that the user is improving (e.g., because the game was often in the exert mode) or worsening, it requires to modify the difficulty level associated with each game mode. In this way, a trained user playing in the keep mode will exercise faster than an untrained user in the same mode, i.e., the difficulty level of the game mode will correspond to the actual fitness of the user.

3.3 The Games Subsystem

The Games subsystem runs the chosen game and changes the graphics and gameplay according to the requests of the Adaptation Engine. In general, changes of mode are mapped into:

- changes in game difficulty (e.g., speed or number of game opponents), that require the user to move faster or slower to progress in the game;
- changes in graphical elements (e.g., background, graphical theme) to make system choices more explicit to the user as well as provide further motivation.

Following this approach, we implemented two fitness games, called *Flareqoor* and *GeoKaos*, which exploit different patterns of movement and present different graphics and gameplay.

GeoKaos (Figure 4) was inspired by the *Arkanoid* [8] arcade game. The user controls a small pad that can be moved horizontally in the bottom of the screen and has to hit a moving white ball, attempting to send it against a number of colored bricks. The ball striking a brick causes the brick to disappear. Moreover, as time passes, the bricks move down. The user loses points if she misses to hit the ball letting it reach the bottom of the screen, or if bricks go under the user's pad. The pad can be moved by performing left or right side jumps: the greater is the jump, the more the pad is moved. Changes in game mode are translated into changes in the ball speed. Moreover, the graphical theme of the game is chosen among three possibilities to make explicit that a game mode change has happened.

Flareqoor (Figure 5) is aspace shoot'emup game. The user moves a continuously firing spaceship (left part of Figure 5) up and down by standing erect or bending knees and has to shoot the enemy spaceships coming from the right. If an enemy spaceship hits the user's spaceship or reaches the left side of the screen, the user loses points, while she gains points by destroying the enemy spaceships. Since the user's spaceship fires continuously, the user has to control only its position by performing knee bends. The speed of enemy spaceships varies with the game mode, and no graphical elements are adapted dynamically.

4 Preliminary evaluation

We carried out a preliminary evaluation of the system on 8 users (4 male, 4 female; age ranging from 23 to 26, averaging at 24.5). Before the experiment,

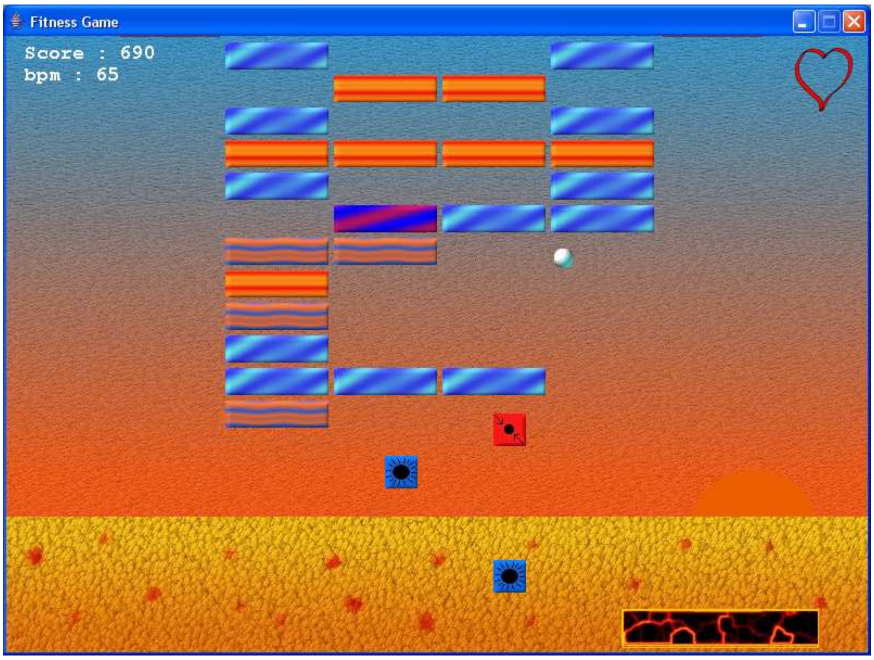

Fig. 4. The GeoKaos game.

Fig. 5. The Flareqoor game.

we acquired personal information (i.e. age, weight and height), and asked users about their experience with videogames and physical activities. In particular, 2 subjects were very familiar with videogames (owning a console and playing at least once a week), 5 occasionally played PC videogames (not every week, but at least once a month), and one very rarely (a few times a year). Only 3 subjects were regularly involved in fitness activities or sports, 2 performed them occasionally (i.e., they sometimes play sports with friends, but they do not regularly train), while 3 did not perform any fitness activity or sport.

Then, users were asked to wear the sensors and try the two games described above. Before each game, we demonstrated the required body movements.

After the experiment, we asked users about their experience with the system. In particular, we asked them (i) to name a few adjectives to describe their overall experience; (ii) to comment on their experience with game control; (iii) to list strengths and weaknesses of the system; (iv) if such a system could motivate them to perform physical activities; (v) which was the game they preferred and why; (vi) if they had any other comment or suggestion to provide.

Considering the first question, 4 users named the adjective *entertaining*, while 3 thought the system was *engaging* and *nice*, but also *fatiguing*. Positive adjectives employed once were *energetic*, *interesting*, *new*, *outstanding*, and *useful*. The only negative adjective was *frustrating* (used only once), used because the game failed to identify movements a few times.

Focusing on game control, all users managed to control the games to a good extent, but five of them complained that they could not always control the game, despite they thought to have performed the correct movement. While this was sometimes due to sensor reading failures, we noticed that at other times it was due to incorrect movements (e.g., knee bends with incorrect spine position or sidesteps instead of side jumps).

With respect to strengths and weaknesses, users liked the idea of combining fitness activity and videogames, and said that the system could motivate them to perform more physical activity. However, 3 users expected more variety in gameplay and graphics, in particular for Flareqoor, which was the less preferred of the two games (only 2 of the 8 users preferred this game), probably because graphical adaptations were absent and thus the game tended to be perceived as boring.

Users provided us also with suggestions to improve the system. In particular, a user suggested us to calculate and display the calories she burnt during the game to provide further motivation, while another user asked for visual in-game demonstrations of the correct movements.

5 Introducing a 3D Virtual Human

As described in the previous section, the evaluation highlighted that some users had difficulties in understanding the correct movements, so in-game advice about them could be a useful improvement. Moreover, reports on the results of the game sessions (e.g., time the user spent in the different game modes) could provide further motivation and make system choices even more explicit. To satisfy these requirements, we introduced a 3D virtual human (Figure 6). When the Adaptation Engine decides that suggestions or demonstrations are needed, the appropriate 3D virtual human animations and speech are retrieved from a database and played to the user.

The virtual human can:

– show the correct movements that control the game (before the game starts, but also during game, if the system detects that the user is not performing movements that can be translated into inputs to the game);
– encourage and motivate the user when game modes are changed, e.g. telling the user that she needs to relax or exercise faster.

Technically, the virtual human is ISO H-Anim [3] compliant with Level of Articulation 2 and implemented in the X3D language [9]. Therefore, it can rotate 71 joints and is thus suited to show how to correctly perform the exercises required to control the games. Moreover, using a 3D model for the virtual human allows us to display the exercise from multiple points of view and thus improve the understanding of the demonstrated exercise.

Fig. 6. The GeoKaos game with the 3D virtual human.

6 Conclusions and future work

In this paper, we proposed a fitness game system which adapts game graphics and gameplay to user's movements and physiological parameters. We implemented two different games with the system and carried out a preliminary evaluation on 8 users, with encouraging outcomes. Since the need for demonstrations of correct movements and in-game advice emerged from the evaluation, we added a 3D virtual human which provides them. However, a more thorough evaluation with users is needed to assess the benefits of the 3D virtual human, and a longitudinal study is required to evaluate long-term effectiveness of the system.

An interesting opportunity for future work is to experiment with more sophisticated adaptations (in graphics and/or gameplay). For example, in more complex games, changes in game mode could be translated into different AI behaviors of opponents, or determine the actions that the user is allowed to perform physically as well as in the game.

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