Chapter 2
Design Issues for Vision-Based Motor-Rehabilitation Serious Games

Antoni Jaume-i-Capó, Biel Moyà-Alcover and Javier Varona

Abstract When rehabilitation sessions are for maintaining capacities, the demotivation of patients is common due to the difficulty in improving their situation. Recent experiments show that rehabilitation results are better when users are motivated and serious games can help to motivate patients in rehabilitation processes. We developed a rehabilitation serious-game for a set of patients who had abandoned therapy due to demotivation in the previous years. The serious-game was developed following desirable features for rehabilitation serious-games presented in the related research works. From this development, we present implementations guidelines for developing serious-games as motivational tool for rehabilitation therapies. The experiments performed in previous works validate that the interacting design issues defined help motivation in therapy and that they are adequate in rehabilitation therapy.

Keywords Serious games · Rehabilitation · Vision-based interfaces

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2.1 Introduction

A serious game [15] is defined as a game that allows the player-user to achieve a specific purpose through the entertainment and engagement component provided by the experience of the game. Recent research [4, 16, 20] shows that the cognitive and motor activity required by video games engage the user's attention. In addition, users focus their attention on the game and this helps them in forgetting that they are in therapy [20, 23]. This motivation is particularly important in long-term rehabilitation for maintaining motor capacities. Demotivation is frequent in chronic patients, because therapy usually consists of repetitive and intensive activities that become boring. As a result, the user may not concentrate on the therapy program which thereby loses its effectiveness.

Therefore, in order to build appropriate serious games for rehabilitation purposes, therapy studies have included the motion-based input devices for serious games, such as *EyeToy*™ [8, 19] or *Wiimote*™ [7]. A common conclusion in previous works is that existing commercial video games for these devices are difficult to use in rehabilitation therapy, because they were designed for patients with full capabilities. Specifically, [2] enumerates the problems associated with commercial video games when used in rehabilitation: targeting mainly upper body gross motor function, lack of support for task customizations, grading, and quantitative measurements. In addition, Sandlund et al. [22] state that patient's interest in gaming faded somewhat over time indicating that there is a need for flexible games that adapt to the changing ability of the user and offer a continuous challenge to maintain the interest. In order to solve these problems, researchers have been developing their own games.

Unfortunately, game-based rehabilitation system designers frequently overemphasize the serious game rather than the user interaction. When these games are designed for disabled people, the interaction design issues are fundamental to achieve a high patient motivation. In addition, game interaction design is usually defined without taking into account user's perceptions with regard to their actions in order to achieve the rehabilitation goals.

Motor rehabilitation usually consists of body movements and patients with motor disabilities can have difficulties holding physical devices. Computer vision technology allows capture body movements and it is non-invasive. For this reason, we built interactive games using computer vision techniques, which can be summarized by capturing the visual information of the performance of user actions.

The experiments performed in previous works [10, 16, 21] validate that the interacting design issues defined help motivation in therapy and that they are adequate in rehabilitation therapy. In this work we present a set of design issues, from our previous work implementing vision-based serious-games for motor rehabilitation.

This work is organized as follows. In Sect. 2.2, we present the previous work. Next, in Sect. 2.3 are presented the design issues. Section 2.4 is devoted to presenting a case study focusing on the design issues. Section 2.5 is dedicated to conclusions.

2.2 Related Work

In previous work, we can find different serious games for different types of rehabilitation. Video games for balance rehabilitation have been presented in [3] where therapy is performed by a center-of-pressure, and the game is designed to older adults in order to incorporate appropriate balance exercises. Regarding upper limb rehabilitation, [14] presented a serious-game based movement therapy which aims to encourage stroke patients with upper limb motor disorders to practice physical exercises, [5] showed Virtual Reality (VR) system for stroke patients, [4] designed several serious games which use low-cost webcams as input technology to capture data of users movements, [6] created a simple game in which the patient tried to move a coloured circle from an initial position to a goal position using a robotic device designed for arm rehabilitation, in [9] implemented a haptic glove serious game for finger flexion and extension therapy, [1] presented several home-based serious games which use a webcam and a *Wiimote*™, and [2] designed a low-cost VR-based system using *Wiimote*™.

Recent research studies have proposed what features are desirable for rehabilitation serious games. [11] proposed target audience, visibility and feedback as important human factors, [4] identified two principles of game design theory which have particular relevance to rehabilitation: meaningful play, the relationship between player's interactions and system reaction, and challenge, maintaining an optimum difficulty is important in order to engage the player. [20] identified as important main criteria for the classification of serious games in the rehabilitation area: application area, interaction technology, game interface, number of players, game genre, adaptability, performance feedback, progress monitoring and game portability. Alankus et al. [1] concluded that serious games must ensure that patients are correctly performing and must provide a motivating context for therapy, in order to have maximum impact on the rehabilitation process.

2.3 Design Issues

From our experience of implementing vision-based motor-rehabilitation serious games [10, 16, 21], defining an interaction model adapted to the user's capabilities and following the desirables features for rehabilitation serious games presented, we can state that success of using this type of serious game depends on 7 design issues: the development paradigm, the interaction mechanism, the interactive elements, the feedback, the adaptability, the monitoring, and the clinical evaluation. These design issues are presented in more detail in the next section.

2.3.1 Development Paradigm

After first meetings with physiotherapists, we discovered that engineering technical language is totally different to physiotherapy. To ensure objectives, we decided to develop the game using the prototype development paradigm [18], which facilitated communication between engineers and physiotherapists. This paradigm ensures all the necessary information to perform the different tasks is provided in a clear and understandable way.

2.3.2 Interaction Mechanism

A serious game should not develop a new rehabilitation therapy. It is more suitable to transfer existing therapy to a serious game, where the selected rehabilitation therapy is the means of interaction with the serious game. As a major number of patients with motor disease cannot hold a device, a camera can be used as an input device in order to define the interaction model adapted to the user's capabilities [17]. Recent technological advances have created the possibility to enhance naturally and significantly the interface perception by means of visual inputs [24], the so-called Vision-Based Interfaces (VBI).

In general, vision-based interaction systems aim to provide reliable computer methods to detect and analyse human movements. The process is repeated over time, allowing for monitoring of the users interacting actions. According to the computer vision technique used it is possible to achieve different levels of detail. In addition, due to the dependence on real conditions (lighting, distances, clothes…) the interaction environment limits the techniques that can be used. Figure 2.1 depicts one example of vision-based interaction which can be implemented by detecting the users silhouette, the skin colour or the hand motion.

2.3.3 Interaction Elements

Interaction objects must be selected in order to show the users images that achieve an optimal level of motivation, by choosing themes of particular interest to each user. When the interaction objects were related to some of these interests [10], the patients performed the rehabilitation activity faster.

2.3.4 Feedback

The game must respond to the actions of the user through different types of feedback, in order to user be aware of their current state. In general, when using VBI with a system [4, 11], providing feedback is critical for users to feel in control

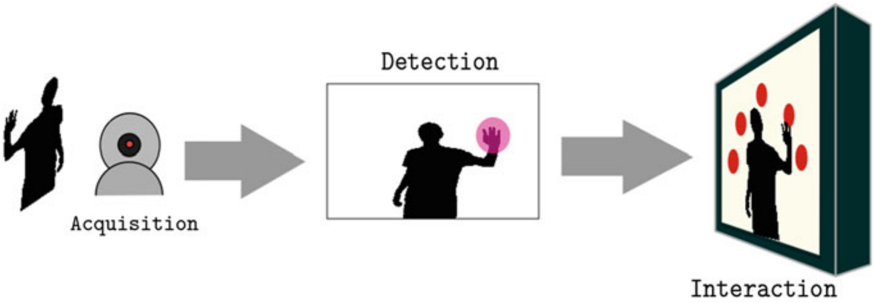


Fig. 2.1 Vision-based interaction which can be implemented by detecting the users silhouette, the skin colour or the hand motion

and helping them to understand what is happening. Especially if there is not contact with the interface by means of an interaction device. A significant problem of vision-based interaction is that users have no interaction device of reference. The user, therefore, always should know when interaction is taking place using visual and audible feedback.

2.3.5 Adaptability

Rehabilitation sessions must adapt to the characteristics of the different users [4, 11, 20]. As the difficult level of therapy depends on the user interaction (motions), physiotherapists should create a set of templates which define the position where interaction elements must have, in order to define different levels in the game depending on the skills and the evolution of each user. In addition, the game should define different configurations parameters to customize games and adapt them to different users.

2.3.6 Monitoring

The system must be able to archive different information about each user, configuration parameters and a dataset for each session consisting of patients performance, in order to simplify a patient's progression as monitored by the specialists [1, 11, 20]. Therefore, the system has two class of users, the patient and the specialist. Each are in pursuit of different objectives of the interaction with the system, see Fig. 2.2.

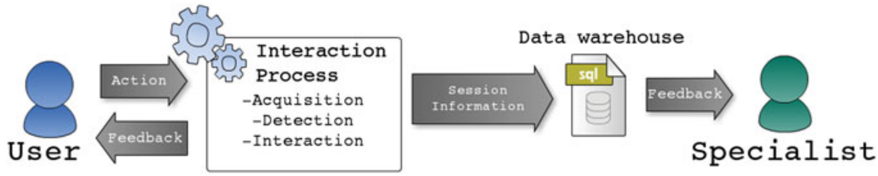


Fig. 2.2 Feedback system depending on user role

2.3.7 Clinical Evaluation

The clinical evaluation aims to quantify the improvement of the rehabilitation according to the kinds of functional exercises. In order to perform a successful clinical evaluation, it should define the experiment, the participants, and the measurements depending on the final goals and type of therapy. However, from our experience, we recommend to design the whole intervention through a pre-assessment and post-assessment of every measurement, see Fig. 2.3. Optimally, the success of clinical evaluation increase when one can include a control group and the largest number of measurements.

2.4 Case Study: Vision-Based Rehabilitation Serious Game

We present a rehabilitation serious game that we implemented for a Cerebral Palsy (CP) rehabilitation center [16]. CP is a term used to describe a group of chronic conditions affecting body movement and muscle coordination. CP is the most common physical disability in children [13]. The number of adults with cerebral palsy is increasing due to increased survival of low birth weight infants, and increased longevity of the adult population. Many children and adults with CP have poor walking abilities and manipulation skills. One of the factors that contributes to their problems with gait and reaching movements is poor balance control. The objectives of medical intervention and physical therapy are to prevent and mitigate the degradation of balance and postural control, in order to conserve autonomy of movement, and to improve muscle coordination when performing voluntary movements.

Each year, part of the center's patients ceased the therapy, after years of rehabilitation sessions to maintain the capacities. The habitual users of the rehabilitation center, are aware that rehabilitation sessions are focused on maintaining capacities, and so they experience demotivation due to the difficulty in improving their situation, and also due to the repetitive nature of the exercises performed in every session. Therefore, the rehabilitation center was interested in a balance rehabilitation serious game to motivate their users, in order to favour coordination and trunk control, to stimulate cognitive and communicative aspects, and improve their activity Activities of Daily Living (ADL).

Fig. 2.3 Visual feedback

2.4.1 Development Paradigm

The serious game was developed using the prototype development paradigm, following requirements indicated by physiotherapists, for a year. During this period, in order to improve the game, the system was tested with real users once a week.

2.4.2 Interaction Mechanism

We selected balance exercises from standard therapy in the rehabilitation room [12], to transfer to a serious game in order to improve balance, to reduce demotivation in patients, and to obtain more adherence to this long-term therapy. The selected balance rehabilitation therapy is the means of interaction with the serious game.

We designed a game which covers the objective required by physiotherapists, which consists in changing the user gravity center, where users stand in front of the standard monitor (or large projector) and, using their movements, they interact with the video game, see Fig. 2.4. In addition, since users may have difficulty in holding devices, the designed game is markerless and device free. With this configuration, users can see the serious game while they are interacting with it. The serious game environment is defined as follows:

- Users must be facing the screen to see the serious game in order to interact using the balance rehabilitation therapy
- Users must see themselves on the screen in order to orient themselves with respect to the interaction objects.

The designed video-game tries to cause a specific body movement in order to change the user gravity center. To do this, the users must interact, by means body movements, with objects they cannot reach without changing their center of mass, see Fig. 2.5. Concretely, the user must delete a set of items that appear on the monitor.

In this way, a user focuses their attention in the serious game instead of their posture, because the goal was not to improve the rehabilitation process, but rather to improve user's motivation.

Fig. 2.4 Game environment configuration

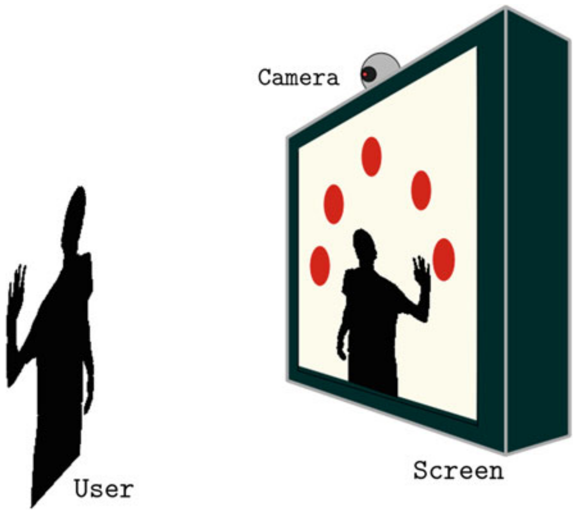
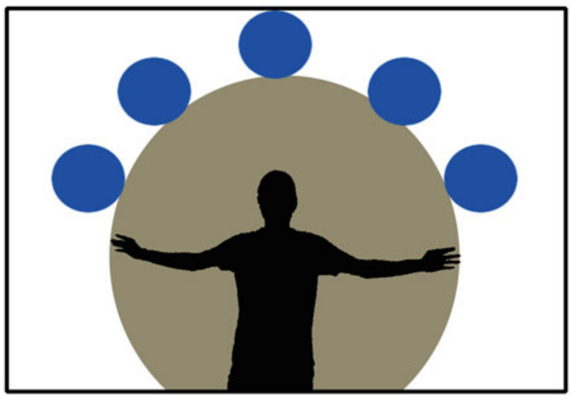


Fig. 2.5 User magnitude without changing center of mass, in *grey*



2.4.3 Feedback

Visual feedback consists of deleting or changing of the object of interaction. Auditory feedback is added in order to reinforce the action result. For example when the interaction object is completely deleted from the screen, an audio feedback is played. And when the game ends, the user receives different types of visual and audio feedback, depending on the end game conditions.

Moreover, we used another type of feedback in VBI, represented by the provision of the visual representation of the users body on the screen, see Fig. 2.6. Users must see themselves on the screen in order to orient themselves with respect to the interaction objects. This configuration allows the user to view the serious game and themselves while performing the interaction.

Fig. 2.6 Visual feedback

2.4.4 Interaction Elements

Interaction elements can be changed in order to show the users' images to achieve an optimal level of motivation. This is by choosing themes of particular interest to each user (see Fig. 2.7). In the study, patients were asked what hobbies they had in order for the designer to seek interaction elements related to these interests.

2.4.5 Adaptability

In order to make rehabilitation sessions adaptable to the characteristics of the different users, a set of templates were created, that define the size and the position that interaction objects must have (see Fig. 2.7), so we can define different levels in the game depending on the skills and the progression of each user. In addition to the patterns, we defined the following configuration parameters to customize games and adapt them to different users:

- *Maximum playing time*: The specialist can set a limit time for each session depending on the users characteristics
- *Mirror effect*: To increase the game difficulty, the game screen can be reversed. So when users move their right hand, they view as if they move their left hand
- *Contact time*: The specialist can customize how long a player must be in contact with an element in order to delete that object
- *User distance*: The distance between user and screen in meters. The larger the distance from the screen, the larger the center-of-mass change needed.

With these implemented adaptability we ensured the *challenge* [4].

Fig. 2.7 Interaction screens with themes for motivating users and different templates

2.4.6 Monitoring

The serious-game saves and maintains an xml file for each user, which is easy to parse and analyse, where configuration parameters and a dataset for each session is stored. This consists of: date of the session, level pattern, playing time, removed percentage, user distance from monitor device and contact time. This way the monitoring of users by the therapists is simplified. This design has the potential to be used in other rehabilitation systems. It is important to remark that there are two types of users: the user and the specialist, with different interaction objectives with the system.

2.4.7 Clinical Evaluation

The research team made a request to all adults in the rehabilitation center who met the inclusion criteria and 90 % agreed to participate in the study. The study population finally included 9 adults, 2 women and 7 men. Their families signed an informed consent.

One of the inclusion criteria was having no adherence to physiotherapy treatment after attending the conventional program of the centre as a long-term therapy. Therefore, patients in this study were undergoing rehabilitation only with our experimental system. This rehabilitation program started after 24 weeks of training, and it consisted of one session per week, during 24 weeks. Before and after the 24 week therapy period, users were pre- and post-assessed using Berg Balance Scale, Functional Reach Test, and Balance Tinetti Test.

Results showed [10, 16] that patients improved their balance slowly; improvements were also detected in individual items. With regards to motivation, in previous years the set of users had abandoned their therapeutic plans. Using the presented video games, no patients abandoned and, on completion of the study, they showed interested in continuing the rehabilitation process with the video games.

2.5 Conclusions

From our previous work implementing vision-based serious-games for motor-rehabilitation, in this work we have presented implementations guidelines for developing vision-based motor-rehabilitation serious games, based on related work and our experience, in order to help others researchers in this field. We can state that the successful of this type of serious games depends on 7 design issues: the development paradigm, the interaction mechanism, the interactive elements, the feedback, the adaptability, the monitoring, and the clinical evaluation.

As a case study, we showed a serious game that we implemented for a CP rehabilitation center, in order to improve patients' balance that consists in changing the user gravity center. The technology employed were vision-based interaction, due to the difficulties of some patients have for holding physical devices. Results showed that patients improved their balance slowly. Regarding motivation, the set of users had resigned their therapeutic plan in previous years. Using the presented video games, no users abandoned and, on completion of the study, they showed interested in continuing the rehabilitation process with the video games.

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