Serious games for physical rehabilitation: designing highly configurable and adaptable games

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ABSTRACT

Computer games have been recognized as a motivational tool in rehabilitation for a decade. Traditional rehabilitation includes exercises which are often considered as repetitive, boring and requires supervision by the therapist. New opportunities in rehabilitation have risen with the emerging popularity of computer games and novel input sensors like 3D cameras, balance boards or accelerometers. Despite active research in this area, there is still lack of available games for rehabilitation mainly due to many different requirements that have to be met for each type of therapy. In this paper we propose a specialized configurable architecture for revalidation games, focusing on neuro-muscular rehabilitation. The proposed architecture enables a therapist to define game controls depending on the patient needs and without any programing skills. We have also implemented a system meeting this architecture and four games using the system in order to verify correctness and functionality of the proposed architecture.

1. INTRODUCTION

Computer games and simulations have been recognized as a motivational tool in rehabilitation (e. g. neuro-rehabilitation, physiotherapy) for several years (Susi, Johannesson, and Backlund 2007; Hocine and Gouaich 2011; Rego, Moreira, and Reis 2010). Classic rehabilitation may include various techniques which are often predictable, repetitive and require practicing at home. Especially in case of physiotherapy and occupational therapy it is important to keep patients motivated and eventually allow them to practice at home without the constant therapist supervision.

An affordable way of developing games for rehabilitation is based on the concept of mini-games. These games can easily overcome diverse shortcomings of commercial games, often encountered when they are practiced by children with special needs (Vero Vanden Abeele et al. 2010). Mini-games can be developed and adjusted relatively quickly. Modern software tools and game engines used by indie game developers speed up the development process from years to months, weeks or even days. However, games used in rehabilitation need additional support, software tools and specialized input devices (van Loon et al. 2011). The lack of these tools makes the development rather complicated.

A huge variety of mini-games is available at low price. Each of these mini-games is usually focused on a specific exercise (Geurts, V Vanden Abeele, and Husson 2011). Consequently, researchers and developers multiply efforts to cover the most frequently used exercises. But, as long as specific hard-coded sensor input methods are used, the application field of the individual games is rather limited. Therapists must pay special attention in selecting the games for specific patient groups in terms of exercises (i.e. speed and range of motion for particular joints during specific motions) and controlling methods (Annema et al. 2010).

Many games that support configuration can only be configured partially and the usage of input sensors often remains hard-coded. In (Geurts et al. 2011) the authors describe 5 mini-games that can be calibrated and adapted for each patient in terms of speed and accuracy. The physical exercise and the input method (in this case the sensors) are static and cannot be replaced.

Although it is reported that such games are helpful in rehabilitation (Standen et al. 2011), no (clinical) analysis at runtime is provided. Such runtime analysis during the gameplay would be helpful in order to evaluate the progress and correctness of the exercise execution and to make suggestions or to provide incentives for corrections. Besides that, data gathered and analysed in long term playing could potentially improve the doctor's information about the patient's state.

In this paper, we propose a specialized configurable architecture for revalidation games, focusing on neuro-muscular rehabilitation. We argue that this architecture increases the usability of exergames and their adaptability for both the patients and the therapists. In addition, it can make the effects of the game playing more transparent to the doctor, by providing the possibility to analyse long term playing.

2. RELATED WORK

Over the last decade, serious games for the rehabilitation have gained popularity and much research was intended to provide evidence of clinical relevance (You et al. 2005; Golomb et al. 2010; Huber et al. 2008), even in in-home use. Consequently, this research often resulted in highly specified games (Geurts et al. 2011) and only rarely with a concept behind these games, their architecture and the specific requirements. J. Perry et al. (Perry et al. 2011) described the typical workflow of such a game as a cyclic process of treatment planning, execution and performance assessment. In addition, they described the user-centric design process that should take a place when designing rehabilitation platforms based on computer games. As a result of the European project PlayMancer (Conconi et al. 2008) a robust Serious Gaming 3D Environment was presented. This environment, containing a hardware abstraction layer and a multimodal dialog manager, enables games to define multiple modalities for interaction in the 3D world. Another recent European project REWIRE, is focusing on building a cheap in-home system for rehabilitation also with an adequate set of mini-games. However, the outcome is not available yet and so it is not clear which modalities they will use and how the modalities will be combined.

3. METHODS

Our proposed design is based on discussions with therapists and patients in order to capture their ideas and fulfil their needs (Perry et al. 2011). The architecture of our system (see Fig. 1) consists of three main layers:

Game controls layer – abstracts hardware devices for the rest of the system. Each input device is represented as a module and can be connected to the system through the unified event-based interface. The modules convert input signals to the uniform format used in the rest of the system. These modules are loaded dynamically at runtime and can be changed without modifying the game even during the gameplay.

Game configuration layer – routes input signals from input modules to the games according to the configuration. This configuration enables a huge variety of possibilities for controlling the game. In addition, each connection between a game and an input module can be monitored by one or more analysers. These analysers can (*i*) track correctness of the physical actions of the patient, (*ii*) influence the score in a game, (*iii*) report measured data from input modules to the doctor (or store them for later assessment).

Games – exposes a binding point to the configuration layer. Each game has to define which elements in the game are controlled by the user. An example could be a game where one direction of a vehicle is controlled. The game itself would only expose a binding point for horizontal movement.

In the beginning, when the game starts, the system loads a configuration stored in the XML file. The configuration is created by the therapist based on the patient needs, using an intuitive user interface for customizing the game towards the needs of the patient. The file contains information about the sensor that the patient should use in order to play the game, the configuration of this sensor, game bindings (information about associations between the input values provided by sensors and the game controls) and analysers that should analyse input values from sensors. When the configuration file is loaded, the system loads an external input module which provides information about the sensor's state and creates game bindings. Then, during the game play, each input module updates the sensor state and passes it to the system through a unified interface. The unified interface guarantees that the input module can be replaced by any other module implementing the same interface (e. g. a 3D camera from one manufacturer can be easily replaced by another camera, released by another manufacturer, without a need to make changes to the game). When the system receives a new input value from the input module (sensor), it passes the value to the game and to the

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analysers depending on the configuration. The game receives a new value also with the information about which control in the game should be updated.

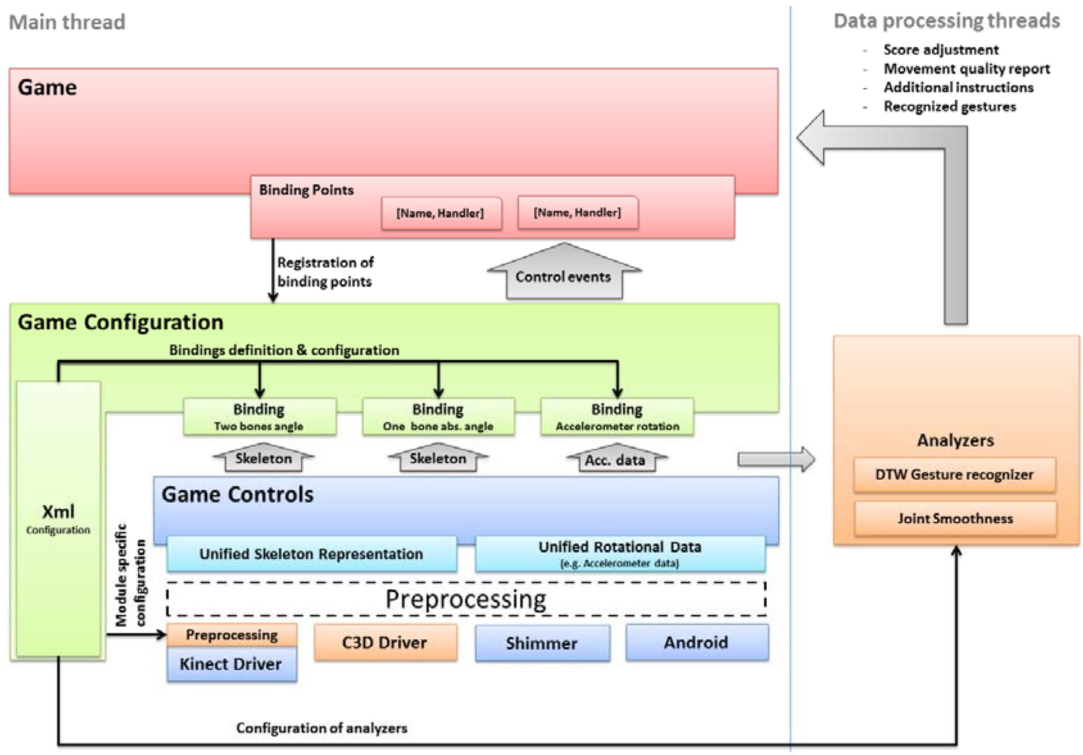


Figure 1. *System architecture.*

4. VALIDATION

In order to validate the proposed architecture we have implemented a system meeting this architecture together with four mini-games using the implemented system (for more information about these mini-games visit the project homepage www.ict4rehab.org). We have also developed a specialised configuration interface through which the therapist can set up the game specifically for each patient. In this section we describe the configuration interface and the minigames and show how they can be reconfigured with respect to the way of controlling.

4.1 Configuration Interface

Serious games have to satisfy special needs and requirements in order to be useful in the rehabilitation (Perry et al. 2011). A large number of the most critical needs, which are not available in the commercial games, can be adjusted in the system (or game) setup and configuration (e.g. calibration on the input, speed of the game). By means of this configuration, various aspects of the games can be personalized, e.g. appropriate challenge, movement analysis, input sensor or state reporting. In order to do so, we have developed a configuration interface (see Fig. 2) which enables users to configure the majority of the settings visually, without programing or designing skills.

Depending on the complexity of the information provided by the sensor (i.e. information on a single segment of the body – as for instance provided by one inertial sensor, or on more segments – as for instance provided by the Kinect), the character in the game can be controlled in more complex manners.

The supported input methods are summarized in Table 1. Each of these input methods provide only a single input value (a floating point number) to the game depending on the configuration. For instance, the game can receive the rotation angle of the specific segment of the human skeleton as a single value, and move the player according to this value. Since the values provided by a sensor might have different scales and a different offset with respect to the neutral position, the therapist can calibrate the input by setting a zero angle (or zero position) and a sensitivity value. Then, the input value *y* provided to the game is computed as follows:

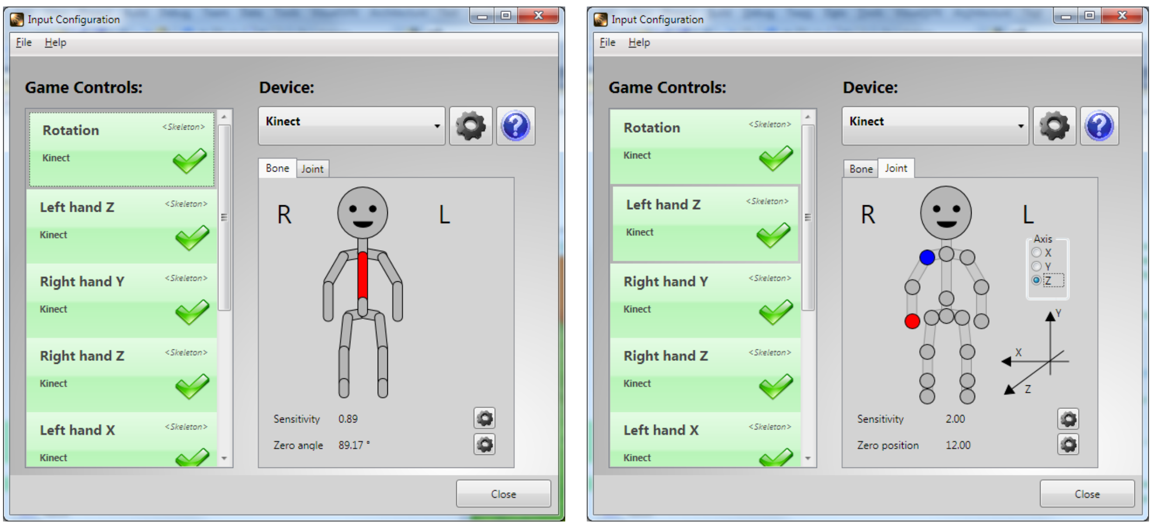
$$y = (x + z) \times s \quad (1)$$

where *x* is the value provided by the sensor, *z* is the zero position (or zero angle) and *s* is the sensitivity. In practice it means that the therapist might configure the position where the player doesn't move (is at the zero position) and range of the movements which the patient have to perform in order to control the game.

Table 1. *Supported input methods with sample use cases.*

Tracked property	Provided input value	Use case
Angle of skeleton segments	Absolute rotation angle of the segment (computed as the angle between the segment and the vector aiming to the left from the camera perspective)	*Horizontal movement of the player on the screen controlled by a lateral movement of the patient's trunk. The angle value is considered as absolute (it means relative to the fixed camera coordinate system), because movements of any other segment (except the trunk) have no influence on the provided angle value.*
	Relative angle between two segments	*Horizontal movement of the player on the screen controlled by the flexion/extension of the elbow. The angle value is computed as the angle between upper and lower arm regardless of the patient's body rotation.*
Position of skeleton joints	Absolute position of the joint (position provided by camera)	*Horizontal movement of the player on the screen controlled by the position of the joint in the scene in front of the sensor (camera). The task for the patient is to place the specific joint (e. g. the wrist) on a certain position with respect to the sensor.*
	Relative position of the defined joint with respect to the predefined base joint	*Horizontal movement of the player on the screen controlled by the relative position of the joint with respect to another joint (e. g. position of the wrist with respect to the shoulder). The task for the patient is to move the wrist to change the distance from the shoulder according to the selected axis.*
Accelerometer rotation	Absolute 3D rotation angle	*Horizontal movement of the player on the screen controlled by a rotation of the sensor. The patient's task in this case is to rotate the sensor according to the selected axis.*

It is important to note that even if our design allows many "unnatural" ways of controlling a game, for some people with disabilities it can be the only possible way for controlling the game. This means that games using this design could be useful not only for the mainstream therapies but also for rare cases which are currently abandoned.



a) b)

Figure 2. *Configuration interface for defining input methods for games; a) input based on the rotation of segments between joints, b) input based on the relative position of joints (red – tracked joint, blue – base joint).*

4.2 *Flying Simulator*

This mini-game (see Fig. 3a) is based on the widely known concept of obstacle avoidance. The game requires players to control a space ship in the horizontal direction. There are two kinds of objects, a rock and a star, approaching the ship. The player's task is to avoid collisions with the rocks and hit approaching stars.

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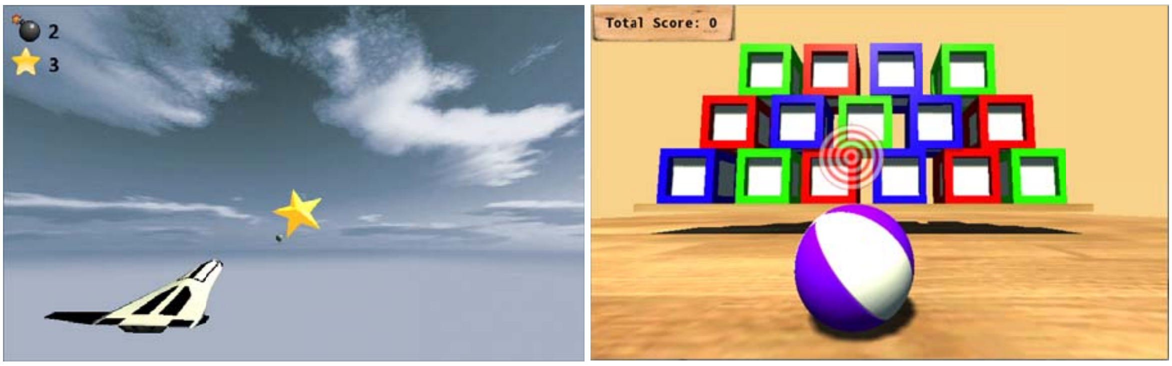
4.3 HitTheBoxes

In the second mini-game (see Fig. 3b) the main task is to control the horizontal movement of the target in front of the shelf full of boxes. There are three types of boxes with different weight and colour. In front of the shelf is also a ball which is periodically thrown after certain time. The player's task is to shed all the boxes from the shelf.



a) b)

Figure 3. *a) Flying simulator game, b) HitTheBoxes game.*

4.4 WipeOut

In the third mini-game (see Fig. 4a) the task is to clean the screen with a rag. In the beginning there is only a dirty screen displayed with the rag in the middle. The player controls the position of the rag (which is possibly bound to the position of a joint, e. g. the hand) to remove the dirt from the screen. As a reward to the player, the picture hidden behind the dirt is uncovered.

4.5 PickThemUp

In the fourth mini-game (see Fig. 4b) the main task is to pick as many mushrooms from the ground as possible. The player controls two gloves (bimanual coordination task) which are mapped to the position of his hands. In one hand (glove) the player is holding a basket. The task is to pick a mushroom from the ground (to move the other hand as close to the mushroom as possible in order to trigger collision which places the mushroom to the hand) and then put it to the basket (again, to move the hand close to the basket).

a) b)

Figure 4. *a) WipeOut game, b) PickThemUp game.*

5. RESULTS

The proposed architecture allows to easily implement a new mini-game with a specific rehabilitation objective for a specific patient group, as all core functionality is provided in a set of core libraries, separating the game input from the different sensors – and even from the regular keyboard and mouse.

We have implemented four different mini-games based on this architecture. Currently we are testing our games with children suffering from cerebral palsy (CP) in order to prove all aspects of the proposed architectural concept and to obtain feedback from clinicians. The testing stage is crucial to the success of the system development and it is essential to be able to contribute fully to the medical community.

As a consequence of the architectural design of our software framework, the developed mini-games will also improve on the current state of the art with respect to rehabilitation schemes: (1) the games can operate with a large range of input sensors (including Kinect and other 3D cameras, accelerometers, balance boards, keyboard, …); (2) the physiotherapist can specify the combination of joints used to control the character (for instance people bound to a wheelchair can "jump" using their arms); (3) the sensitivity of the game to posture changes can be specified (i.e. the difficulty level); (4) the visual complexity of the scene can be configured (cf. cognitive visual impairment in cerebral palsy); (5) real-time simple biomechanical analysis is performed such that the targeted postures cannot simply be mimicked; (6) all these different aspects can be analysed and configured remotely by the physiotherapist.

6. CONCLUSION

In this article, a novel configurable architecture for revalidation games was presented. The architecture was designed by considering its suitability and requirements – usability, functionality and acceptability (Perry et al. 2011). We have implemented a system that meets the proposed architecture together with four games. These games have been tested with children suffering from CP and with their therapists. During these tests we observed a significant potential of our approach for building serious games and a positive feedback from both, patients and therapists. We have also observed several limitations that outline our future work.

Even though we provide the specialized configuration interface for defining various input methods visually, setting all parameters is a time consuming task. Moreover correct values of parameters vary depending on the specific game. In order to make it even easier to use, we are working on a collection of pre-defined configurations, covering selected exercises in the CP rehabilitation.

Playing these mini-games appears to be a real motivation for users, but it should be a therapy in the first place. Sensors should provide accurate measurements to assess the correctness of exercises and to make the gameplay (and background analyses) clinically relevant.

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