Towards Procedural Level Generation for Rehabilitation

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ABSTRACT

This paper introduces the concept of procedural content generation for physical rehabilitation. In this initial study a ski-slalom game is developed on the Wii platform that procedurally places the gates of the game according to player performance. A preliminary game evaluation study is conducted on patients with injured legs and showcases the efficiency of the procedural gate generation mechanism tailoring the game difficulty to match rehabilitation goals. The study also validates certain usability aspects of the patients.

Categories and Subject Descriptors

I.2.1 [**Artificial Intelligence**]: Applications and Expert Systems—*Games*; H.1.2 [**Models and Principles**]: User — Machine Systems—*Human factors*

Keywords

Procedural level generation, Wiihabilitation

1. INTRODUCTION

The Nintendo Wii game console is the best-selling console available today [3] utilizing physical interaction via controllers such as the Wii Remote and the Wii Balance Board. The Wii Balance Board allows game interaction through foot pressure and body weight balancing on the board. These features push video game design to incorporate body movement as a key control modality. In particular, *Wii Sports* (2006) constitutes of different sport games such as boxing, bowling, golf, and tennis in which the player's avatar can be controlled via a physical motion, e.g. bowling using the Wii Remote. In *We Ski* (2008), the player is skiing by controlling the pressure on the Wii Balance Board. On that basis, Wii technology gives players new motivations to immerse themselves both mentally and physically. This has inspired many hospitals and rehabilitation centers in the USA [14] to use existing Wii physical games for rehabilitation purposes. The use of Wii technology for physical rehabilitation is also known as *Wiihabilitation*.

Existing commercial Wii games, however, are not designed for rehabilitation which, in turn, may over-challenge people with partly disabled extremities. Moreover, different patients have different rehabilitation goals to reach and a fixed Wii game does not tailor the gameplay for the patient to meet specific rehabilitation milestones. A solution to those usability problems would be the development of an adaptive Wii physical game that can adjust game parameters to match the patient's physical ability level.

The main aim of this initial study is the development and evaluation of an adaptive Wii game for rehabilitation, which can procedurally generate content in real-time and, furthermore, provide effective training to each patient given the level of her physical ability. For this purpose, an adaptive ski-slalom game played with the Wii Balance Board is developed and tested on patients of a rehabilitation center. The game procedurally generates the placement of the slalom gates based on heuristics of player performance. The preliminary user study presented here reveals that the game adjusts the ski-slalom track effectively to match patient skills. This paper is novel in that it introduces the concept of procedural content generation (PCG) and player modeling for physical rehabilitation utilizing the Wii Balance Board.

2. BACKGROUND

Research in physical rehabilitation [1, 5] has shown that exercises for patients recovering from physical disabilities and injuries are more effective when the exercises are integrated within a game. Patients get more engaged and motivated through a game environment and they tend to forget the pain caused by and the dull repetitive nature of rehabilitation exercises. Physical interactivity, portability, low-cost and commercial availability make the Wii Remote and Wii Balance Board the ideal controllers for developing physical rehabilitation games [8].

With the popularization of physical interactive game platforms considerable research has been conducted for capturing player immersion [11], engagement [2] and player affective states [7, 16] in physical interactive games. On the

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Figure 1: A screenshot of the ReSkii game.

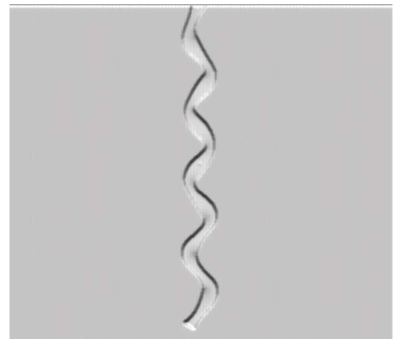

Figure 2: The ReSkii level from top-down view.

other hand, very few studies investigate the design of adaptive mechanisms for maximizing player experience in such augmented-reality game platforms [16].

PCG in games has been used for a wide variety of purposes including terrain [6, 10] and space [9] generation, environmental modeling [13], and race track [15] generation. However, to the best of the authors' knowledge there has been no study investigating procedurally generated content for Wii games and its impact to the rehabilitation process.

3. THE RESKII GAME

Interviews were conducted with physiotherapists to assist the design of the Wiihabilitation game. The design of the final test-bed game is based on the physiotherapists' knowledge and observations about their patients recovering from leg injuries. The following research hypotheses were formed on the basis of those interviews:

- H1: Foot pressure performance is lower on injured or partly-disabled legs (e.g. a patient with a right leg disability is expected to miss more right turns in a ski-slalom game).
- H2: Foot pressure performance is increased in easier tasks (e.g. easier right ski-slaloms will improve the score of a player with a right leg injury)
- H3: Gradually increasing the difficulty of a game task will force the player to exercise with the problematic leg thereby accelerating rehabilitation.

In order to validate the stated hypotheses and demonstrate the impact of adaptation and PCG on rehabilitation we developed a test-bed game. It was our aim that the developed PCG game will not only accelerate the rehabilitation process but also make exercises more fun to execute. The game should be able to recognize the patient's playing style, identify the difficulties faced during the game and procedurally generate a level that forces the patient to train her injured leg(s) better.

Skiing games are appropriate for both balance and persistence training (We Ski is already used in several rehabilitation centers globally) while the Wii Balance Board is suitable for engaging the lower part of the patient's body in physical activity. Based on the above-mentioned design principles, we developed the *ReSkii* game (see Figure 1). ReSkii is a single level ski-slalom game (see Figure 1) implemented on the 3D engine Unity3D and played with the Wii Balance Board controller. Vital elements of the level are generated procedurally in real-time (during gameplay). In this initial study the position of the right (red) and left (blue) gates are procedurally placed according to a player performance function.

The performance function is built on the player motion track during gameplay. The ski-motion tracks are generated by applying left and right leg pressure forces on the board controller. In this initial study a simple evaluation of the player's performance on left and right leg is implemented, that is based on the success of reaching left and right gates, respectively. The performance measure, named *penalty score*, is calculated every time the player passes through (successful pass) or next to (unsuccessful pass) a gate:

$$P^{dir} = \begin{cases} 0, & \text{if successful pass} \\ E^{dir}, & \text{otherwise} \end{cases} \quad (1)$$

where $dir = \{left, right\}$ and $E^{dir} = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$ is the euclidian distance from the passing point to the closest pole of the dir (left or right) gate. The penalty score, P, is a value calculated independently for right and left gates and represents the success of the player's skiing ability on each leg which furthermore yields the basis of the PCG mechanism proposed in this paper. Since the gates are placed alternately, left and right from the center of the track, persistent pressure force is needed on the leg in the direction of the gate in order to reach it. Therefore, the P values for left and right gates encapsulate the players' ability to have persistent pressure on the corresponding legs; if a player has a physical impairment on a leg, the penalty score for that leg should therefore be higher. Alternatively, other performance measures could be investigated that would consider the detailed motion patterns during gameplay (e.g. shifting the center of gravity from left to right and vice versa).

The level terrain is generated once at the beginning of the game using four-point Catmull-Rom Splines which create the zig-zag pattern seen in Figure 2. Gates are placed at a fixed offset of three meters along the x-axis from the generated spline. The level is divided into a number of sections equal to the number of track turns (Figure 2) within which the P values are calculated and aggregated. The division of the level into sections is essential for PCG since the zig-zag nature of the track does not allow visibility of the gate placement procedurality. At the end of each section the game dynamically adds alternating gates along the next section with a varying distance among them. In partic-

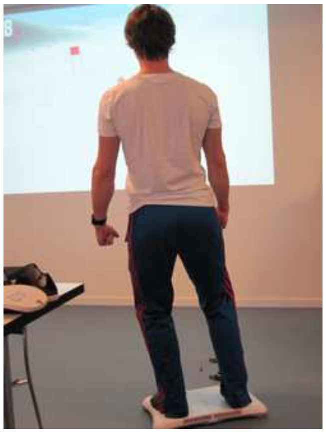

Figure 3: Control subject playing ReSkii.

ular the P^{left} value calculated during the previous section will determine the distance D^{left} between the right and left gates while the corresponding P^{right} value will determine the distance D^{right} as follows:

$$D^{dir} = P_N^{dir}(d_{max} - d_{min}) + d_{min} \quad (2)$$

where $dir = \{left, right\}$; P_N^{dir} is the normalized P value that lies between 0 and 1 and d_{max} and d_{min} are respectively the maximum and minimum distance offset values — d_{max} equals 15 meters and d_{min} equals 5 meters in this paper.

Equation 2 indicates that the distance offset between left and right gates along the y axis is increased when the player is performing poorly on the left and right gate respectively. On the contrary, good performance leads to y-offset (D^{dir}) decrease. This initial adaptation rule generates personalized gameplay via keeping the game challenge within the abilities of the patient. Furthermore, the matching between challenge and player skills aims at maintaining the gameplay within the flow channel [4].

4. USER STUDY

Two patients, a 66-year old male weighing 78 Kg and a 60-year old female weighing 92 Kg, have participated in the experiments reported here. The subjects played two games each. According to their physiotherapist, both subjects had a right leg injury at the time of the experiment. Moreover, a male subject, aged 25 and weighing 88 kg, with great physical health (being an athlete and physiotherapist) played a level of ReSkii and was used as the baseline/control subject of this study. The player's position and the raw Wii Balance Board data (pressure force on all four sensors of the board) are stored at a frequency of **6**0 Hz during gameplay. The time and the penalty score, P, are stored every time the player passes through or misses a gate.

Results obtained from all four patients and the control subject are summarized in Figure 4 and Table 1. Figure 4 depicts the ski routes and the penalty score over time for all subjects that participated in the experiment while Table 1 presents a number of statistical features for all games played.

It is apparent that both patient subjects (in both games played) generate a higher penalty score for the right than for the left leg; not surprisingly this observation is consistent with their reported physical disability (right leg injury). On the contrary, the corresponding P values for the control

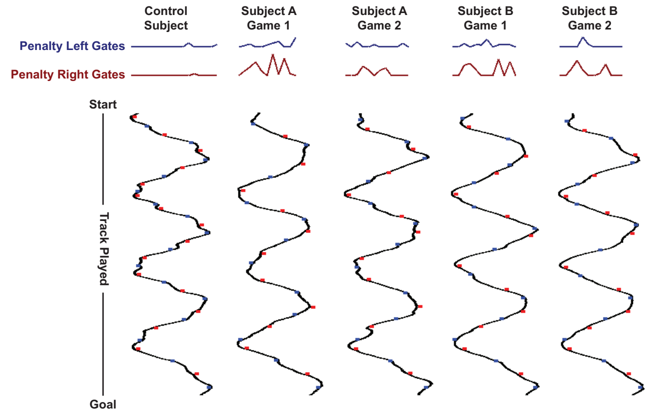

Figure 4: Track overview and penalty scores over time for all experiment participants. Blue and red squares indicate left and right gate.

subject are close to zero. Moreover, as seen in Figure 4 high P values result to the generation of easier (smoother) levels through gate placement. Low P values, on the other hand, generate rather difficult and noisy ski tracks.

By looking at the figures of Table 1 one can deduct that test subjects stand more on their non-problematic (left) leg indicated by the average center of their gravity ($\overline{G}$) throughout the game. It is also worth noticing that the two subjects stand more on the left leg the more they play since $\overline{G}$ is higher at the second game played.

Surprisingly, it appears that both subjects put more pressure on average on the balance board via their partly-disabled right than via their healthy left foot on both games played. It was observed, however, that patients found it hard to keep a constant pressure with their injured leg; thus, in order to play the ReSkii game well they had to press harder with that leg within shorter time periods. That playing behavior yields higher maximum and average pressure recorded on the right leg. The fluctuations of the pressure forces are also indicated by the higher standard deviation of the pressure force values ($\sigma\{F\}$) on the right Wii Balance Board sensors.

Testing of our research hypotheses formed in section 3 reveals that H1 is validated through the increased penalty values on the injured leg of the patients. H2 appears to be valid since playing performance increases with respect to the order of play for both patients; however, learnability and game control familiarity effects might also be present and need to be investigated in a future study. Finally, H3 needs to be validated with additional experiments over longer periods of training.

5. DISCUSSION AND CONCLUSIONS

This is an initial study investigating the interplay between procedural level generation and player profiling on physical Wii games developed for physical rehabilitation. The adaptive mechanism proposed adjusts elements of a skiing game (ReSkii) for the purpose of personalizing the rehabilitation process via PCG. For the gameplay experience to be personalized, patient characteristics are captured during play and guide PCG. Results indicate that it is possible to build simple, yet successful, computational models of physical interaction of patients with partial leg disabilities and proce-

Table 1: **Subject (control, A and B) statistics of pressure force (F), penalty score (P) and center of gravity (G). Maximum, average and standard deviation of F and average P are calculated independently for each leg; the average center of gravity ($\overline{G}$) is a value that lies between -1 and 1 the sign of which indicates the placement of the center of gravity: left ($-$) or right ($+$) leg.**

	Control		Subject A				Subject B			
	Game 1		Game 1		Game 2		Game 1		Game 2	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
$\max\{F\}$ (Kg)	64,34	53,31	52,50	58,95	54,65	55,87	52,54	62,04	51,59	54,95
$\overline{F}$ (Kg)	38,89	42,45	34,38	40,08	35.29	39,08	45.02	44.30	44.17	45.12
$\sigma\{F\}$ (Kg)	3,33	3,29	3,74	3,93	5,48	5,59	1,99	2,04	1,96	2,01
$\overline{P}$	9.73	2.67	35.57	103.12	21.70	40.92	31.94	83.26	17.68	57.65
$\overline{G}$	−0.19		−0.07		−0.28		−0.35		−0.43	

durally generate appropriate game levels for their needs.

To increase the effectiveness of the training, patients' physiological responses such as heart rate and skin conductance may be measured and embedded as additional inputs to the level generation mechanism. Moreover, to keep the levels interesting and the game immersive for the player over extended periods of rehabilitation, more elements can be added or procedurally generated in the game such as narrative, level geometry, jumps and multiple-track choices. More sophisticated algorithms for modeling playing behavior (e.g. via patient preference learning [12]) as well as richer PCG mechanisms (e.g. via ski track evolution [15]) will be investigated in future studies and integrated in the ReSkii game. Such patient models could identify more types of physical disability a patient might have, measure the patient's performance based on multiple gameplay characteristics and thereby evaluate better the "goodness" of content that is procedurally generated within the game level.

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