Therapeutic games' difficulty adaptation: An approach based on player's ability and motivation

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An Approach Based on Player's Ability and Motivation

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Abstract—**Therapeutic games can be considered as a promising rehabilitation tool since they provide personalized rehabilitation sessions in which training intensity and challenges can be adapted to the patient's ability, motivation and performance. In this paper, we discuss post-stroke therapeutic game design challenges and requirements that open-up a variety of adaptation issues. Our objective is to present a generic difficulty adaptation technique for a family of post-stroke upper-limb rehabilitation games. The proposed technique aims to increase rehabilitation volume by maintaining patients' motivation and engagement.**

Therapeutic game, Difficulty adaptation.

I. INTRODUCTION

Therapeutic serious game can be considered as an interesting and a promising rehabilitation tool. Indeed, therapeutic games help to create a motivating rehabilitation environment which gives meaning to physical and cognitive rehabilitation exercises. The benefit of therapeutic games is twofold since; on the one hand, (i) they can improve patients' rehabilitation volume which consequently increase their chances of skills' recovery, and on the other hand (ii) help therapists to have quantitative measures about patients' performance to rationalize and steer rehabilitation strategies.

Most rehabilitation techniques are founded on the principles of motor learning and skill acquisition established for the healthy nervous system. These studies suggest that intensive training (several repetitions) while giving feedbacks and motivating patients can have an important impact on patients' skills recovery [3][11]. In fact, during the rehabilitation process, stroke patients often recover slowly some of their motor abilities. With repeated therapeutic activities, they usually become tired and frustrated. Thus their motivation has to be supported alongside the rehabilitation sessions.

Hence, the potential benefit of training based on a serious game strategy relies on creating a personalized rehabilitation environment. In this way, the training intensity, duration, challenges and frequency can be manipulated and enhanced. This manipulation could be used in order to motivate the patient by creating a personalized motor learning paradigm. This can avoid the patient's non-commitment and frustration, which is a key to recovery. A person who enjoys what he is doing spends more time developing his/ her skills in a given activity.

In this paper, we present a generic difficulty adaptation technique based on player's ability and motivation. The proposed adaptation technique has been initially experimented on some healthy people using a simple wii-board based balance game. In the rest of this paper, we present some therapeutic game design requirements and challenges that steer the discussion of the proposed difficulty adaptation approach. An illustration of the wii-board based game and the conduced pilot experiment are also provided in order to explain how this approach has been conducted. Finally, we conclude this paper by discussing the pilot experiment results and explaining our future works.

II. POST-STROKE THERAPEUTIC GAME DESIGN CHALLENGES AND REQUIREMENTS

The personalized motor learning in a serious game rehabilitation strategy can be achieved through an appropriate user-centered game design. The latter must meet accurate, personal, and therapeutic objectives. Actually, in traditional rehabilitation strategy, therapists try to improve patients' functional skills such as movement amplitude, direction and smoothness by proposing to them for instance to reach or grasp an object on a table. Therapists try to train patients by adapting the activities to their abilities and current health conditions, while supporting them by giving some feedbacks. Patients repeat these activities during their daily rehabilitation sessions which should last for five weeks at least. Among the most important challenges that we have identified in our research study is the therapeutic game *playability*. It is the condition that the serious game must fulfill to be considered a useful rehabilitation tool. In other words, the latter should meet therapeutic requirements and needs while satisfying the player and keeping him engaged in the therapy.

As patients' motivation and engagement are required to improve their rehabilitation volume, a therapeutic serious game should meet the following most important game design requirements:

- *Ability assessment:* the patient performance can vary as it depends on his/her health condition. Accordingly, if the therapeutic game has not properly assessed the patient's health condition, it is highly possible that the patient will not succeed in the proposed activity, decreasing therefore his motivation to continue the therapy.

- *Variability:* introducing variability in games and tasks is important as it can motivate patients and helps them not to feel bored following repeated therapeutic activities in their daily rehabilitation sessions.
- *Difficulty adjustment and game continuity:* adapting the game tasks to patients' abilities and rehabilitation needs can be considered among the most important therapeutic requirements. It also avoids facing the patient with an unbroken situation of failure.

In order to meet these requirements, an adaptive approach should be considered in the early stages of the therapeutic game design. To be efficient, adaptivity also needs to be steered by game design aspects. In fact, it is necessary to take into account the task variability, patient's ability assessment and the decision making possibilities of the difficulty adjustment during the game session.

III. RELATED WORKS

The game difficulty is often considered among the most important attributes that determine the fun and enjoyment of the game [14]. From a game design point of view, the game's difficulty level can be designed either statically or dynamically. The static approach is an objective determination of the difficulty level. In this case, the player can choose manually his/her game's difficulty level, or it is the game that will push him to follow a series of difficulty levels according to his/her performance. The dynamic approach focuses on adapting the game to the player's progress, status and performance during the game experience [6]. In this respect, we come across works on dynamic difficulty adaptation of entertainment games (or DDA for Dynamic Difficulty Adjustment) that consider the difficulty as a heuristic function that depends on game metrics [9][17]. We also find techniques founded on the dynamic creation of games' narratives and scenarios [15] and the creation of strategies [6] that are often based on players' profile and situations (for more information about the literature review see [8]). The player in this case fails when he reaches a point where the difficulty level is beyond his capabilities.

In fitness or sport games, the motivation is generally related to the fun aspect of the game. It has to do with performing physical exercises that are attractive and may easily engage people [10][2]. For instance, Buttussi et al, [2] propose fitness games using physiological and motion sensors. The adaptation mechanism depends on changing the graphics and difficulty of the game related to the player's heart rate.

In the context of post-stroke rehabilitation using virtual reality or serious game strategy, most therapeutic games proposed in the literature are founded on static determination of tasks and game difficulty by therapists [1]. For example, Heuser et al [7] suggest five therapeutic games exercises. Each exercise involves a set of difficulty levels following patient's recovery. The difficulty level is designed in a static manner. Thus, when the patient fails as the difficulty level exceeds his capabilities, the simulation stops the exercise.

Chen Y. et al [4] put forward a framework for media adaptation in task-oriented neuromotor rehabilitation based on biofeedbacks. Scenery images and their clarity, sounds variety and music instruments are used to reflect the arm movement, which can be an interesting way to adapt feedbacks. The adaptation strategy depends on the choice of the musical instrument, tempo variation and task difficulty which is annotated by the therapist. Finally, Ma et al, [13] suggest an in-between approach. The therapeutic game aims to improve functional arm capabilities, visual discrimination, and selective attention using three difficulty levels: Beginner, Intermediate and Expert. The system suggests a difficulty level to the patient according to his profile data. The adaptation technique is based on a specification matrix that determines the relationship between the patient's profile and the difficulty level. Furthermore, the adaptation technique does not take into account the in-game player's health conditions, such as his tardiness and his motivation.

IV. PROPOSITION

This section describes the proposed adaptation approach which aims to meet the therapeutic game design requirements.

A. *Player's Profile and the Abilities Assessment Step*

In order to make decisions concerning therapeutic objectives, therapists use generally clinical test scores, such as *Fugl-Meyer* score, or a kinematic based evaluation in virtual reality or robotic aided therapy. As for serious game, a kinematic based evaluation can be used, and especially in our approach, the assessment step is included in the game. The game proposes to the player to reach some targets placed in different positions in the 2D plane. The player's profile contains his/ her ability data as well as general information about the player such as his/her age, gender, and whether he/she is right or left hander, impaired side, stroke date, *Fugl-Meyer* score, and neglect side. The player's profile is used then to choose the appropriate adaptation strategy according to the proposed game goal associated with the therapeutic objective.

B. *Therapeutic Game Abstract Model and the Proposed Wii-Balance Game*

Rehabilitation needs a variation of game themes and ambiances to avoid monotony and consequently patient's demotivation. However, although the theme and ambiance of the game can be changed, the therapeutic objectives and strategies have to be maintained, i.e. they have to be independent from the actual game level. Consequently, two levels have been identified: (i) an abstract movement level and (ii) an actual game level. The abstract movement level considers the mechanics of patients' movement and their relationship to therapeutic objectives; the actual game level chooses a context and defines the meaning of the abstract level. For instance, at the abstract movement level the objective can be to reach a target point starting from a source point. This can be translated differently in games such as catch an animated rabbit or a ball in a game's virtual environment. In this paper, only pointing tasks, where the patient is asked to reach a target, are considered. Indeed, for post-stroke rehabilitation this represents the most important rehabilitation phase. When the patient is able to achieve pointing tasks, then the therapists can focus on other types of tasks such as grasping.

In order to experiment the adaptation technique we have chosen a game based on movements coordination on a 2D plane similar to the ones patients could encounter during their upper-limb rehabilitation programs. The proposed balance game is based on wii-board device. However, the wii-board was used with hands and not with feet. The proposed game aims to improve player's equilibrium capabilities while achieving the game goals. It is based on a task-oriented structure in which the goal is to stabilize a ball closest to a target (a cube) within a limited time. Depending on the target's location the player may find it more or less difficult to stabilize the ball (see Figure 1).

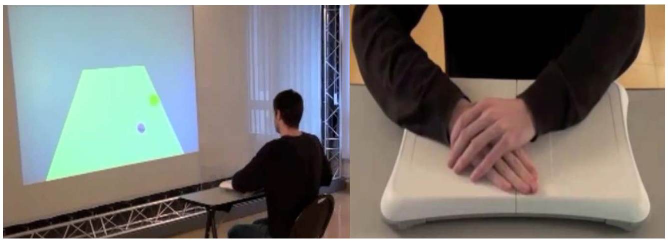

Figure 1. A player tries to stabilize the vitual ball using Wiiborad from Nintendo (Wii-balance game)

C. *General Difficulty Adaptation Framework*

The rationale behind the proposed approach is presented in Figure 2. Once a therapeutic objective is defined for a rehabilitation session (for example: increasing the range and smoothness of the impaired arm movement), the therapist chooses a sequence of therapeutic games that fulfill this objective. The patient-game interaction generates a set of observable data that are collected and referred to generically as performance. The adaptation module uses this data to adjust the player's task difficulty.

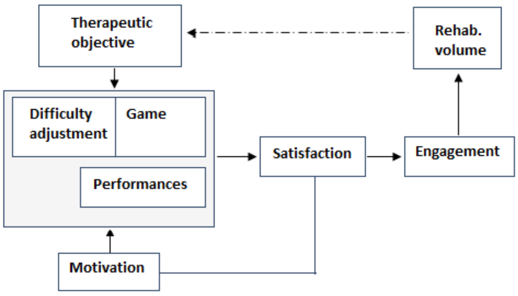

Figure 2. General difficulty adaptation framework

Our approach of motivation is inspired from job satisfaction theory [12]. In this approach, motivation is mainly considered as a regulation process. When the reality (outcome of a therapeutic game) is consistent with the expectations of the patient (perception of own motor skills) then this is considered as a stabilized satisfaction state. The patient endeavors to maintain this steady state. In the case of a minor disruption (constructive dissatisfaction), the patient may make efforts to regulate his satisfaction state. The difficulty adaptation module is asked to come up with constructive dissatisfaction situations to keep the patient engaged in the therapy, which can increase the rehabilitation volume (i.e the total time and number of therapy session) Thus, in order to meet the difficulty adjustment and continuity requirements, we focus on a difficulty adaptation based on player's motivation model. The latter is derived from the activation theory [16] which states that stimulation is necessary and the use of an activation level is required in order to motivate an individual to perform his tasks. This theory seems to be adequate for use in therapeutic game context where the stimulation can be controlled by adjusting the difficulty level.

As a measure of the activation level, we have considered the ratio between the probability of accumulated successes and failures for a patient [16]:

$$Activation\ (n) = \begin{cases} \log\left(\dfrac{\Pr_n(success)}{1-\Pr_{n-1}(success)}\right) & \text{if } \Pr_n(success) \neq 1 \\ 1 & \text{otherwise} \end{cases}$$

$\Pr_n(success)$ represents the proportion of successful tasks of all prior games.

The cumulative activation score is simply a sum of all activation scores:

$$\delta(n) = \sum_{i=1}^{n} Activation(i)$$

This measure helps to record all activation scores achieved by the patient. It provides a global trend of the motivation that is not affected by local variations.

To represent local variations, we introduce also a derivative measure on activation scores:

$$\delta(n) = Activation\ (n) - Activation\ (n-1)$$

This measure indicates the direction of the current motivation score when compared to the previous one.

D. *Abstract Model for Difficulty Adaptation*

As previously mentioned, it is important to consider the difficulty adaptation module at the abstract level in order to reuse it in different games. For this purpose, we introduce a structure called: *matrix of action probabilities*. This matrix represents the 2D plane of game and each place $D_{(i,j)}$ holds a probability that an action should be performed at this location by the patient. Using this information, the game level has to direct game actions towards places of highest probabilities. The advantage of this structure is to offer a common interface to all games. Thus, the game level considers the difficulty adaptation module as a black box producing a matrix of action probabilities.

To make the matrix of action probabilities while taking into consideration difficulty adaptation in game, it is necessary to collect some information about the patient. This step is called the *assessment* and produces a matrix where each place $A_{(i,j)}$ represents a success rate of the patient. Finally, the difficulty level is expressed as a desired success probability *d* to accomplish a task by the patient. In other words, the game proposes a difficulty while the probability of success is estimated by *d%* at least. In this case, the relationship between the two matrices is as follows:

$$D_{(i,j)} = \begin{cases} \dfrac{1}{\#\{A(x,y) \geq d\}} & if\left(A_{(i,j)} \geq d\right) \\ 0 & if\left(A_{(i,j)} \prec d\right) \end{cases}$$

Where # denotes the cardinal of a set (number of elements)

This means that all places where the patient is supposed to succeed with at least a ratio of *d* are selected with adequacy equi probabilities. All other places are given probability of *0* since the game level ignores them.

E. Difficulty Adaptation Process

In our approach, the difficulty of a task is related with its probability of success. Higher success probability indicates low difficulty and the contrary is still true. According to the patients' profile and motivation, the difficulty adaptation module makes one of the following decisions: increase, decrease or maintain the current difficulty level of the training session.

Three criteria are taken into account when adjusting the difficulty level: the first two criteria $S+_{local}(n), S-_{local}(n)$ measure the local instability of the motivation in both increase and decrease directions respectively. The third criterion measures the overall trend of motivation. These criteria are calculated as follow:

$$S-_{local}(n) = \frac{\#\{\delta(i) \prec 0, i \in [n-\omega, n]\}}{\omega} \prec \omega^{+}{}_{local}$$

$$S+_{local}(n) = \frac{\#\{\delta(i) \geq 0, i \in [n-\omega, n]\}}{\omega} \prec \omega^{-}{}_{local}$$

$$T_{global}(n) = Trend(\sigma(1), \sigma(n) \geq \omega_{trend}$$

ω is a parameter that determines the size of the window to calculate the local fluctuation of motivation. $\omega^{-}{}_{local}$ and $\omega^{+}{}_{local}$ determines the threshold of success and failure ratios in the local window. T_{global} represents overall trend of motivation. A least squares method is used to calculate this trend on the cumulative motivation.

With these elements, the algorithm makes the following decisions:

- $S-_{local}(n) \wedge \neg T_{global}(n)$: decrease the difficulty. Indeed, this is interpreted as a local decrease in motivation and a global trend indicating demotivation.
- $S+_{local}(n) \wedge T_{global}(n)$: increase the difficulty. This is interpreted as a local and global increase in motivation: the patient is succeeding too easily. The difficulty is increased to keep an acceptable level of challenge.
- In other cases, do not change the difficulty.

V. THE PILOT EXPERIMENT

To experiment the present adaptation approach we have conducted a pilot study with healthy players. In fact, before experimenting on patients and interrupt their classical rehabilitation program (planned for five weeks at least), it is necessary to experiment firstly on healthy persons. Nonetheless, the experiment scheme on healthy players has to simulate difficulty conditions- based on movements' coordination on a 2D plane- similar to the ones that patients could encounter during their upper-limb rehabilitation program. The suggested game's task difficulty levels are adapted to healthy player, and thus the game is considered in this case as a training tool for them.

A. Protocol and Hypothesis

The aim of this experiment is to demonstrate that the proposed motivation-based difficulty adjustment technique influences the players' motivation and their perceived difficulties. Our objective is to create a game experience in which we (i) provide task difficulties which are appropriate to the players' capabilities in order to train them and thus improve their motor skills acquisition (ii) support players' motivation by (a) maintaining the balance between success and failure rate while creating constructive dissatisfactions and (b) influencing positively the perceived difficulty.

The experiment follows independent-measures design for two independent groups. Group 1 uses the proposed difficulty adaptation technique and Group 2 uses a random task difficulty. For both groups the experiment was conducted in a similar way. The player's profile contains data about patient's equilibrium capabilities collected during the assessment step. This initial assessment also produces the difficulty matrix for the first round of the game. In addition, at the end of each round player's performance are used by the system in order to generate the task difficulty for the next round. Besides, at the end of each round, the player reports on his/her own perceived difficulty using the DP-15 scale [5].

Each group consists of four people with the following characteristics:

TABLE I. PILOT EXPRIMENT PARTICIPANTS

Group	Gender	Age	Dominant hand
1	3M 1F	23.25 (± 3.59)	4 right
2	3M 1F	24.25 (± 2.22)	3 right and 1 left

In order to check the success and failure rates' proprieties and the system influence on perceived difficulty, the following hypotheses are stated:

A.H0 There is no balance between success and failure proportion in Group 1 as well as in Group 2.

B.H0 The perceived difficulty in Group 1 is different from Group 2.

B. Results

All statistical analysis were performed using R (http://www.r-project.org) version 2.12.0. Chi-square goodness of fit test in order to reject A.H0 and t-test to reject B.H0.

The motivation model parameters has been set experimentally as follows: $\omega = 5$, $\omega^{-}{}_{local} = \omega^{+}{}_{local} = 0.6$ =, $T_{global} = .25$

TABLE II. SUCCESS AND FAILURE RATE

Group	Success	Failure
1	48,871%	51,128%
2	69,322%	30,678%

Only Group 1 which uses the difficulty adaptation strategy strikes a balance between success and failure proportion propriety. The χ^2 rejects so A.H0 as success and failure proportion are both approximately 50% in Group1. As for Group 2, the hypothesis cannot be rejected using this test.

Furthermore, the t-test shows that the perceived difficulty has been approximately the same in both groups, t=0.2641, df=6 and standard error of difference= 0.946. Hence, the B.H0 has also been rejected. These results indicate that dynamic difficulty adjustment influences the player's motivation not only by challenging him (see game motivation concepts [14]) but also by maintaining his success rate and influencing his perceived difficulty.

Despite the use of a strategy based on challenging the player through maintaining his dissatisfaction and satisfaction, which causes a high failure rate versus the non adaptive technique, the perceived difficulty has been nearly the same in both groups. In fact, the proposed technique allows challenging the player without frustrating or boring him/her. Actually, this can be performed by maintaining the balance between success and failure rate in the game session and decreasing the level of the player's perceived difficulty.

VI. CONCLUSION

In this paper, we described a generic dynamic difficulty adaptation approach for pointing tasks in therapeutic games. We have explained how this approach can meet therapeutic requirements such as: (i) the ability assessment: by proposing an in-game kinematic evaluation mechanism taken from traditional rehabilitation practices, (ii) the variability: by introducing a game abstract level which provide various ambiances and task theme with the same therapeutic objective behind (iii) difficulty adjustment and continuity, by introducing a dynamic difficulty adaptation technique founded on a motivation model and the assessment of player's capabilities, which aims to overcome the playability challenge. As stroke patients' failure rate is usually high in their daily rehabilitation, our adaptation technique could show its potential by decreasing the perceived tasks' difficulty and avoid facing the player with a situation of failure, maintaining therefore his motivation to continue the therapy. Finally, for this experiment we used healthy people, once the motivation model is more stable we want to test it on stroke patients. In this case, we will keep the same collecting data principles with some additions to suit the users' profiles such as general data concerning the time since the stroke, impaired limb side, neglect side. These indicators could be used by the adaptation module to choose the appropriate strategy according to the proposed therapeutic objective.

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REFERENCES

[1] G. Alankus, A. Lazar, M. May and C. Kelleher, “Towards customizable games for stroke rehabilitation”, In Proceedings of the 28th international conference on Human factors in computing systems, ACM, 2113-2122, 2010.

[2] F. Buttussi, L. Chittaro, R. Ranon and A. Verona, “Adaptation of graphics and gameplay in fitness games by exploiting motion and physiological sensors”, Smart Graphics, 2007, pp.85–96.

[3] M. Cirstea and M. Levin, Improvement of arm movement patterns and endpoint control, Neurorehabilitation and Neural Repair, 2007.

[4] Y. Chen, W. Xu, H. Sundaram,T. Rikakis and S. Liu, “A dynamic decision network framework for online media adaptation in stroke rehabilitation”, ACM Transactions on Multimedia Computing, Communications, and Applications (TOMCCAP), ACM, , 2008, pp.1–38.

[5] D. Delignieres, “La perception de la difficulte dans les taches motrices”, HDR, Montpellier 1 University, 1996.

[6] N. Georgios, G. Yannakakis and J. Hallam: “Real-time Adaptation of Augmented-Reality Games for Optimizing Player Satisfaction”, IEEE, 2008.

[7] A. Heuser, H. Kourtev, S. Winter, D. Fensterheim, G. Burdea, V. Hentz and P. Forducey, “Tele-Rehabilitation using the Rutgers Master II glove following Carpal Tunnel Release surgery”, In 2006 International Workshop on Virtual Rehabilitation, IEEE publisher, 2006, pp.88–93.

[8] N. Hocine, A. Gouaich, I. Di Loreto and L. Abrouk, “Etat de l'art des techniques d'adaptation dans les jeux ludiques et serieux”. Sepecial issue in Artificial intellegence review, 2011, pp.253–280.

[9] R. Hunicke and V. Chapman, “AI for Dynamic Difficulty Adjustment in Games”, Challenges in Game Artificial Intelligence AAAI Workshop, AAAI Press, San Jose, , 2004, pp.91–96.

[10] W. IJsselsteijn, Y. de Kort, J. Westerink, M. de Jager and R. Bonants, “Fun and sports: Enhancing the home fitness experience”, In Rauterberg, M. (ed.) ICEC, 2004.

[11] M. Levin, H. Sveistrup and S. Subramanian, “Feedback and virtual environments for motor learning and rehabilitation”, Schedae, 1, 2010, pp.19–36.

[12] C. Levy-Leboyer, “Re-motiver au travail. Developper l'implication de ses collaborateurs”, Paris: edition d'organisation, 2007.

[13] M. Ma, D. Charles,S. McDonough, J. Crosbie, L. Oliver and C. “McGoldrick Adaptive virtual reality games for rehabilitation of motor disorders”, Universal Access in Human-Computer Interaction, Ambient Interaction, 2007.

[14] T. Malone and M. Lepper, “Making learning fun: A taxonomy of intrinsic motivations for learning”, In R. E. Snow and M. J. Farr (Eds.), Aptitude, learning and instruction, Hillsdale, NJ: Lawrence Erlbaum Associates, 1987.

[15] S. Natkin, and C. Yan, S. Jumpertz, and B. Market, “Creating Multiplayer Ubiquitous Games using an adaptive narration model based on a user's model”, Digital Games Research Association International Conference (DiGRA 2007), 2007.

[16] W. Scott, “Activation theory and task design”, Organizational Behavior and Human Performance, 1,1966, pp.3–30.

[17] P. Spronck , I.Sprinkhuizen-Kuyper and E. Postma, “Difficulty Scaling of Game AI”, Proceedings of the 5th International Conference on Intelligent Games and Simulation, 2004, Belgium, pp. 33–37.