Emotion-enabled Haptic-based Serious Game for Post Stroke Rehabilitation

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Abstract

In this paper, we propose and develop a novel adaptive haptic- based serious game for post stroke rehabilitation. Real-time patients emotions monitoring based on the Electroencephalogram (EEG) is used as an additional game control. A subject-dependent algorithm recognizing negative and positive emotions from EEG is integrated. Force feedback is proposed and implemented in the game. The proposed EEG-enabled haptic-based serious game could help to promote rehabilitation of the patients with motor deficits after stroke. Such games could be used by the patients for post stroke rehabilitation even at home convenience without a nurse presence.

CR Categories: H.5.2 [Software Engineering]: User Interfaces—Haptic I/O I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality I.5 [Pattern Recognition]: Applications—Signal processing;

Keywords: EEG, haptics, serious game, rehabilitation, emotion monitoring

1 Introduction

In recent years, easily available new technologies such as Electroencephalogram (EEG) reading devices and haptic devices brought new opportunities in serious game design and development. EEG is a non-invasive technique recording the electrical potential over the scalp which is produced by the activities of brain cortex, and reflects the state of the brain [Nunez and Srinivasan 2006]. EEG technique gives us an easy and portable way to monitor brain activities such as the users emotions [Liu et al. 2010] and level of concentration [Wang et al. 2011] by using suitable signal processing and classification methods and algorithms. Haptic devices give the user an opportunity "to feel" the simulated virtual environment in the way similar to the real world. For example, the user could feel the weight of objects in virtual worlds or the forces of the objects interaction. Thus, the user could have a possibility to act in the game in a similar way as in the real world. Using technologies such as EEG reading devices and haptic devices allow proposing new approaches in serious game design and development [Wang et al. 2011; Hou and Sourina 2010; Palluel-Germain et al. 2007; Minchev et al. 2009].

In this paper, we propose a novel adaptive haptic-based post stroke rehabilitation game with emotions monitoring. Stroke is the leading cause of serious, long-term disability in the United States [Kochanek et al.]. Each year, more than 700,000 people suffer a stroke in US. Stroke not only causes physical discomfort, but also interferes with social relationships, family life and self- esteem. "Rehabilitation helps stroke survivors relearn skills that are lost when part of their brains is damaged. For some stroke survivors, rehabilitation will be an on-going process to maintain and refine skills and could involve working with specialists for months or years after the stroke" [NINDS]. That is why, it is important to propose new treatments that need less assistance from therapists. Current treatments for stroke rehabilitation employ multidisciplinary approaches such as chemical (drugs), physical (therapeutic exercise, acupuncture, etc.), psychological approach (relaxation with music, etc.) or a combination of the above-mentioned approaches. Physical exercises need engagement of the nurse who can access the physical and mental state of the patient during the exercise and/or assist the patient during the rehabilitation session. There are three types of motion exercises: a passive range of motion, an active assistive range of motion, and an active range of motion [Mangusan]. In the first case, the patient can move his/her body parts by him/herself if possible (for example, with the healthy hand) or only with the help of the nurse. In the second type of the exercises, the nurse assists in the exercises, for example, to lift the arms if the patient can move the arm only partially. During the third type of exercises named active range of motion, the patient can do the movements without assistance but still the nurse presence could be needed to monitor the patients mental state and his/her recovery progress. All exercises should help to promote joint flexibility, strengthening, increase in muscular endurance, coordination and even improve the patients emotional state.

Since it is often difficult to maintain the patients motivation with the traditional stroke rehabilitation exercises, there is a need for research on novel technologies and game design. These technologies may be effective in optimizing the patients engagement during the rehabilitation process. There are several games for upper limb post-stroke rehabilitation which use novel technology such as webcam images, Nintendo Wii technology, etc [Xu et al. 2010; Joo et al. 2010; Saposnik et al. 2010]. The main advantages of such games are that the patients profile can be automatically stored including the patients reaching ability, play time, scores and so on. Although a great improvement is reported when haptic devices were used in the games [Alamri et al. 2008; Lovquist and Dreifaldt 2006; Broeren et al. 2008], fundamental research is still needed to validate clinical experiments. In this paper, we propose to integrate novel interaction technologies such as haptic interface and EEG-based interface to improve engagement of users in the game. The users emotions recognized from EEG are used as an additional game control to adapt the game level. Emotion recognition algorithms with adequate accuracy are needed to be implemented to make the game fully adaptive to the patient mental state. In this paper, we propose and develop a multi-level computer game Basket following the traditional rehabilitation exercise that consists from putting different objects into the basket in the predefined time. The objectives of the proposed game are to aid the patients concentration, upper limb strength at the same time monitoring the users emotional state and adapting the game level according to the patient current emotion and score.

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2 Methods and Materials

The proposed and implemented game combines haptic-enabled 3-dimensional physically-based virtual environment and real-time emotion monitoring based on the users EEG. The following two devices are used: an EEG device and a haptic device. The overall diagram of the game design is shown in Figure 1. After the game starts, in the EEG pipeline, raw EEG signals read from the user are filtered and analyzed by an emotion recognition algorithm, and the resulting parameter such as negative or positive emotion is passed to the game control module. Meanwhile, the player uses his/her hand to control the haptic device in the physically-based virtual environment. The haptic rendering module reads the position, orientation and control command from the haptic interface, then the haptic interaction force is calculated and is conveyed to the user through the haptic device. The game score is calculated and recorded during the haptic manipulation.

The game control module checks the user's score and emotional statistics on the completion of the current level of the game and automatically adapts the difficulty level of the next round of the game. Thus, the decision about the next difficulty level is made based on the player's score and the emotion dominated during the current game level. This is especially important for rehabilitation games as negative emotions could eliminate the therapeutic effect of the game or even harm the patients health. If the negative emotion dominates, the game goes to the easy level if the score is low or stays at the same level if the score is high or even is terminated in the case of exceeding the time limit for negative emotions. The nurse could be called if the game is played in the hospital environment.

A therapeutic effect of the game is achieved by combination of the physical exercise done by the patient using haptic device with force feedback and the user's emotion monitoring. The target of the game is not only to do prescribed physical exercises but at the same time stay positive during the exercise. To implement the user's emotions monitoring, a real-time emotion recognition algorithms is needed to be integrated. Real-time EEG-based emotion recognition algorithms development and its integration in the game design is a new challenging multidisciplinary research topic. In work [Liu and Sourina 2012], an emotion recognition algorithm was proposed. The algorithm can recognize up to 8 emotions such as happy, surprised, satisfied, protected, angry, fear, unconcerned, and sad in Valence-Arousal-Dominance emotion model. The algorithm consists of two parts: features extraction and classification. The combination of features such as statistical and fractal dimension features proposed in work [Liu and Sourina 2012] to achieve the best accuracy and then elaborated in work [Liu and Sourina 2013] is chosen for the algorithm implementation in our game.

The patient plays the game with the force feedback that is felt through the haptic device. CHAI 3D library is chosen for the game implementation. It is an open-source framework for haptics and dynamics simulation. The library is able to integrate Open Dynamics Engine (ODE) which is used to model physical properties of 3D objects, for example, to assign weights to the objects in the developed game. The dynamic engine provides the user with a full immersion experience of the physical virtual environment that could improve the therapeutic effect of the game.

3 Results

In order to play the developed emotion-enabled haptic based game, the user needs EEG reading device, haptic device, and PC computer. EEG data is read by Emotiv device with 14 electrodes locating at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8,

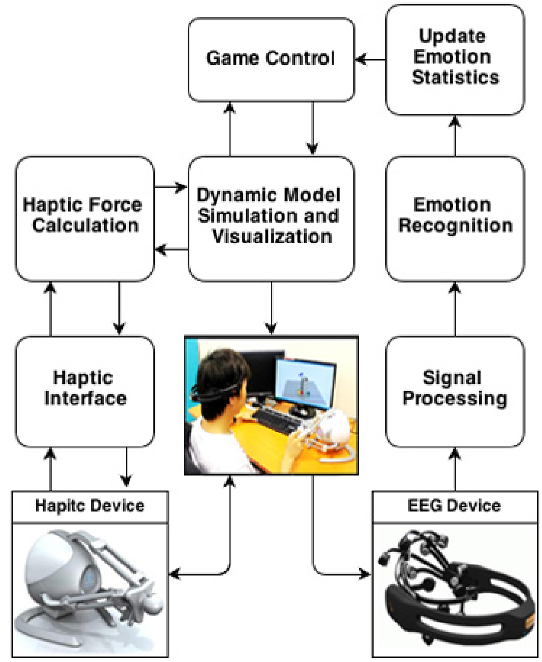


Figure 1: *The overall diagram of the EEG-enabled and haptic-based serious game.*

AF4 standardized by the American Electroencephalographic Society [Sharbrough et al. 1991] (plus CMS/DRL as references). The technical parameters of the device are given as follows: bandwidth 0.2-45Hz, digital notch filters at 50Hz and 60Hz; A/D converter with16 bits resolution and sampling rate of 128Hz. NOVINT Falcon device is used for haptic feedback in the game. EEG signal is transmitted to the computer with Bluetooth. The data is filtered with bandpass filter 2-42 Hz. After that, statistical features and fractal dimension values are calculated with algorithms implemented with the sliding window of 512 samples size. Then, based on the emotion recognized and the score gained by the user the command to the game is given. The Basket game is developed with the realistic graphics and friendly user interface.

The scoring system is implemented to keep the track of the patient's performance and time spent for each level. Currently, three levels of the game are implemented. The patient has to pick up objects and put them into the basket using the haptic device. For each successful object being picked and put into the basket, the points are rewarded. The objects have different appearance (color and shape) to entertain the user. Different weight and size are assigned to the 3D objects at different levels of difficulty to make exercises more challenging at different levels. For example, the basket could become wider or narrower in different difficulty levels depending on the user's performance and emotions. The moving between the levels depends on the user's time spent for the completing the task and emotional state. Conditions for changing the difficulty levels are shown in Table 1. At each level, high or low score can be achieved. The score for each level is calculated based on the time spent by the player and the number of objects collected in the basket. If the player puts all objects into the basket in the predefined time, the high score is assigned to the player. If the player exceeds the time the low score is assigned. There is also the overall time limit for playing the game and overall time limit if negative emotion is dominant through the game. In such case, the game is stopped. If negative or positive emotion is recognized and occupies more than 50% of the playing time at the current level, this emotion is con-

Score	Dominant emotion	Difficulty level of the next round
High	Negative	Same level
High	Positive	Higher level
Low	Negative	Lower level
Low	Positive	Same level

Table 1: *Decision for changing the difficulty levels of the "Basket" game.*

sidered as the dominant emotion. If the user completes the current game level in the appropriate time but the emotional state is negative one then the game is continued at the same difficulty level but with more fancy shapes and colors and at the same time the music is played to improve the player's mood. If emotions are positive during the game then the game level changes to higher or lower difficulty level directly according to the player's score. The design of the game follows the rules and regulations in maintaining the standard procedure of progressive recuperation.

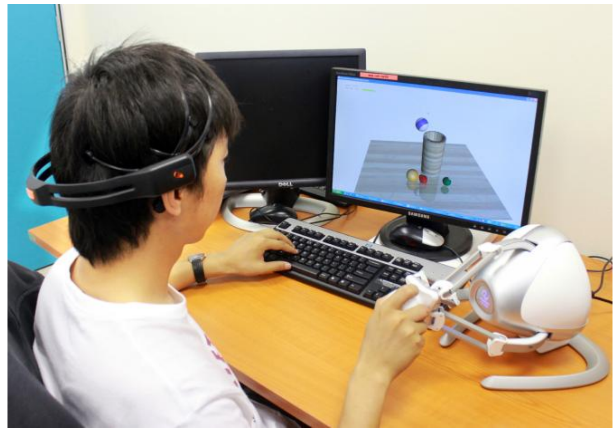
In Figure 2(a), an example of the game setting with EEG and haptic devices is shown. The Emotiv device is mounted on the patient's head for his/her real-time emotion monitoring. The user plays the game using NOVINT Falcon haptic device. The player has to put different objects into the basket. In Figure 2(b), the screenshot of the highest difficulty level 3 is shown when the objects are heaver and the basket is smaller.

Currently, the Basket game is implemented to promote only active range of motions. The final objective is to implement series of Basket games corresponding to passive and active range of motions as well.

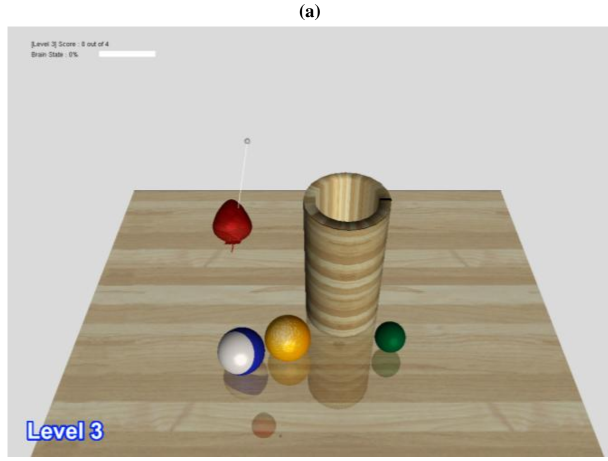
4 Discussion

The EEG-enabled haptic-based serious game for stroke rehabilitation could be played by the patient not only in the presence of the nurse but at home convenience as well. The proposed game is adapted to the current emotional state of the patient that is very important for post stroke therapy efficiency improvement. Currently, the game was tested by 3 students (23-25 years old) and by one post stroke patient (69 years old) to get the preliminary feedback on the game. The post stroke patient gave

the following positive comments comparing to the traditional Basket non-computer game he used for his rehabilitation: a better choice of objects in the computer game, automatic tracking the play time, automatic score keeping, and finally, a positive feedback to the user. More research should be done in future on the assessment of the therapeutic effect of the game with more subjects, and statistics should be collected. Currently, the implemented game is targeting active range of motion. As the haptic technology is involved in the game, it could be possible to implement passive range of motion and active assistive range of motion that usually are used at early stages of post stroke rehabilitation. The proposed game could be used as a part of the home-based rehabilitation programs. Thus, we proposed a cost-effective EEG-based and haptic- based technology combination for post stroke rehabilitation. The cost of the developed software is included in the current project cost and can be minimized just to the cost of CD copy. The final cost of the treatment could include one EEG headset, one haptic device with access to PC computer that currently has a tendency to reduce. Then, the patient could have any number of sessions prescribed by the doctor free of charge. As the game is adaptive to the user's abilities, the length of the sessions and the level of difficulty could be changed according to the monitored patient's emotional state and



(a)



(b)

Figure 2: *The "Basket" game with EEG and haptic devices.(a) User with EEG and haptic device. (b) The highest difficulty level of the game: a small basket and four objects with different mass values*

the score gained. Considering all above the proposed post stroke rehabilitation tools could improve the quality of life giving the patients a good alternative to more expensive traditional treatments.

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