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Development of engagement evaluation method and learning mechanism in an engagement enhancing rehabilitation system

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ABSTRACT

Maintaining and enhancing engagement of patients during stroke rehabilitation exercises are in the focus of current research. There have been various methods and computer supported tools developed for this purpose, which try to avoid mundane exercising that is prone to become a routine or even boring for the patients and leads to ineffective training. This paper proposes a strategy bundle-based smart learning mechanism (SLM) to increase the efficiency of rehabilitation exercises. The underpinning strategy considers motor, perceptive, cognitive and emotional aspects of engagement. Part of a cyber-physical stroke rehabilitation system (CP-SRS), the proposed SLM is able to learn the relationship between the actual engagement levels and applied stimulations. From a computational point of view, the SLM is based on multiplexed signal processing and a machine learning agent. The paper presents the mathematical concepts of signal processing, the reasoning algorithms, and the overall embedding of the SLM in the CP-SRS. Regression and classification are two possible solutions for this learning mechanism. Computer simulation is conducted to investigate the limitations of the proposed learning mechanism and compare the results of different machine learning methods. We simulate regression with artificial neural network (ANN), and classification with ANN and Naive Bayes (NB). Results show that classification with NB is more promising in practice since it is less sensitive to the deviations in the inputs than the applied version of ANN.

1. Introduction

1.1. Setting the stage

Maintaining and enhancing patient's engagement in stroke rehabilitation exercises are in the focus of current research. It has been demonstrated through evidence that it can remarkably improve the functional outcome of technology-assisted stroke rehabilitation (e.g., Prange et al., 2006, Henderson et al., 2007; Kwakkel et al., 2008). Furthermore, the recent findings of research suggest that active participation during rehabilitation promotes cortical plasticity, which may lead to restoring motor abilities (Fiedler et al., 2000; Lynskey et al., 2008). Active participation in rehabilitation appears to be much more than just a patient attending a therapy. Studies also have showed that active participation depends on multiple elements, including the attitude of patients toward attending the therapy, the level of understanding, and the perceived need for treatment (e.g., Jeffrey, 1981, Geelen and Soons, 1996; Maclean et al., 2000). Therefore, the most up-to-date conceptualization of the engagement challenge extends the construct of participation well beyond therapy attendance and instinctive motivation, and directly addresses the role and the quality of engagement of the patients in the short and long term rehabilitation processes (Kortte et al., 2007).

In the context of rehabilitation exercises, engagement has been defined as a construct that is driven by motivation and executed through active and effortful participation (Lequerica and Kortte, 2010). Although stroke patients are required to proactively and intensively participate during the rehabilitation program, it does not mean that they are engaged. The difference between participation and engagement in this context is that engagement involves high levels of invested interest (Lequerica and Kortte, 2010). Therefore, increasing engagement has been considered to be crucial in terms of the outcomes of rehabilitation (Langhorne et al., 2011).

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1.2. Concise overview of the related literature

There have been various methods and computer supported tools developed for trying to avoid mundane exercising that is prone to become a routine or even boring for the patients and leads to ineffective training. Several studies applied serious gaming (Burke et al., 2009), collaborative tele-rehabilitation (Loureiro et al., 2006) and virtual reality (Zimmerli et al., 2013) to increase patient's engagement during the training exercises. However, none of these studies applied intervention during training exercises in order to maintain the user's engagement. Even the best engagement methods such as serious games need to cope with decrease of engagement as the users get familiar with the game (Li et al., 2014a). We argue that with continuous monitoring on the engagement level and introducing interventions during rehabilitation exercises the engagement of patients can be maintained.

Another limitation is that the methods developed to evaluate and measure engagement are subjective and qualitative. The same patient's engagement could be different according to different therapists, which leads to inaccurate assessment. In addition, without precise measurement, the methods to engage the user cannot be validated. In education, several studies evaluated student's engagement using postures (D'Mello et al., 2007; Sanghvi et al., 2011), body motion (Sanghvi et al., 2011) or log files in e-learning system (Cocea and Weibelzahl, 2007). But engagement evaluation depends on context, so evaluation of rehabilitation engagement should consider indicators in the rehabilitation context. Kortte et al. developed an engagement rating scale, which took rehabilitation engagement, therapy absences, functional status, emotional functioning, affective state, level of functioning and denial into consideration (Kortte et al., 2007). Although they tried to evaluate the engagement from all the necessary aspects, the scale was rated by occupational therapists, which could be subjective and different according to different therapists. Szafir and Mutlu developed an adaptive agent that monitors the cognitive engagement of students and improves their engagement during learning (Szafir and Mutlu, 2012). They use EEG to quantitatively represent the engagement level of students. The adaptive agent is implemented as robotic instructor capable to give immediacy cues triggered by drops in EEG-monitored engagement levels to regain participant attention. Although this method is very promising in education, in the context of rehabilitation a more comprehensive characterization of the engagement that monitors not only the cognitive engagement of patients, but also the motor, emotional and perceptive engagement.

1.3. Structure and content of the rest of the paper

The objective of this paper is to propose a smart learning mechanism (SLM) to learn the relationship between the stimulations and changes of engagement level, and make decisions on the most suitable stimulations when the engagement level decreases. The next section first introduces the concept of the whole system, CP-SRS, and then proposes a method to capture and represent the patient's engagement level in motor, perceptive, cognitive and emotional aspects. The third section introduces the stimulation strategies and the reasoning and realization of the SLM. Finally a computer simulation is conducted aiming at a limit analysis and validation of the SLM concept.

2. System concept and capturing engagement levels

2.1. Concept and operation flow of the cyber-physical stroke rehabilitation system

The overall objective of our background research is development and validation of a cyber-physical stroke rehabilitation system (CP-SRS) which is composed of four subsystems, namely, assistive robotic subsystem, gamification subsystem, engagement evaluating and smart learning mechanism subsystem, and engagement enhancement subsystem (Fig. 1). Specifically, the assistive robotic subsystem assists the stroke survivors to make exercises during rehabilitation program in order to reduce deficits in their motor ability. Gamification subsystem integrates video games with the motor training and enables human computer interaction (Li et al., 2014b). This paper will focus on the third subsystem which evaluates the engagement level and uses the SLM to make suggestions on the most suitable stimulation strategies to engage the patient. These stimulations will be realized in the engagement enhancement subsystem.

One of the main constituents of this system is the SLM, which is able to suggest suitable strategies to increase the efficiency of rehabilitation exercises. The underpinning strategy considers motor, perceptive, cognitive and emotional aspects of engagement. As a reasoning engine of the CP-SRS, the proposed SLM is able to learn the relationship between the actual engagement levels from these aspects and the stimulation strategies. The operation flow of how this subsystem works is as follows (Fig. 2). First, the system monitors the patient's engagement level and represents his/her engagement level in four aspects, which will be discussed in detail later. If there is a decrease in the engagement level, the system applies stimulation strategies in order to stimulate the patient. Then the SLM will learn the relationship between the stimulations and the engagement level changes. In the next stage, when the system detects the engagement level decrease, the SLM can act as an artificial expert to suggest the most suitable stimulation strategies. The stimulation strategies are reflected and realized in the game exercise. After each exercise, the system evaluates the effectiveness of the stimulation strategies and refines the SLM in order to train the learning mechanism to be more accurate.

2.2. Capturing and representing engagement levels

2.2.1. Indicator of motor engagement

Motor engagement (ME) is defined as the normalized root mean square (RMS) of electromyography (EMG) signals. RMS is considered to be the most meaningful calculation of the amplitude of the EMG signal, since it gives a measure of the power of the signal. Researchers found that three kinematic properties, namely velocity, amplitude and loads, influence the intensity of EMG

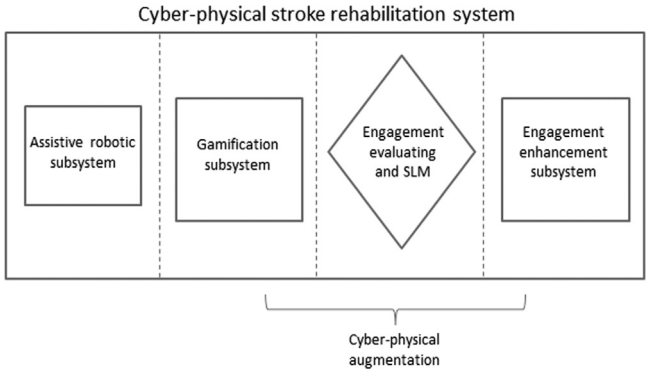

Fig. 1. System concept.