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Automated Personalized Exposure Therapy Based on Physiological Measures Using Experience-Driven Procedural Content Generation

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Abstract

Our research focuses on personalized virtual reality exposure therapy (VRET) based on the Experience-Driven Procedural Content Generation (EDPCG) framework. There are existing approaches for personalized VRET; however, they are subjective and require hand-authored and predefined rules that may not generalize to all subjects. We propose a framework to personalize VRET based on predicting subjects' experiences via physiological sensors and machine learning algorithms. The framework then automatically adapts exposure parameters based on the subject's physiological response using a PCG method. We intend to conduct two human subject studies for arachnophobia and fear of public speaking.

Introduction

Exposure therapy is known as the most effective psychological treatment to reduce fear and anxiety responses, and decrease avoidance (Abramowitz, Deacon, and Whiteside 2019). In this therapy, a subject is gradually exposed to a feared situation or object in a safe environment, learning to become less sensitive over time. Studies show that exposure therapy should be ideally personalized to better fit patients' needs as it leads to more effective outcomes (Smits, Powers, and Otto 2019).

Prevailing personalized technology-based exposure therapies require manual modification of exposure parameters by a therapist to satisfy individual needs. For example, in (Rizzo et al. 2014) study, the therapist can introduce more provocative elements in a combat-related VR environment for patients with Post-Traumatic Stress Disorder.

There is prior work on automatically adapting these parameters; however, they rely on hand-authored, predefined rules, which may not generalize to all individuals. Automated game content generation techniques could be a promising approach for personalized exposure therapy. These approaches generate automated customized content in real-time based on user experience and preference. Specifically, Experience-driven Procedural Content Generation (EDPCG) (Yannakakis and Togelius 2015) provides a framework for systematically creating and modifying content to optimize a user's experience (could be equivalent to therapy experience).

There are several approaches for obtaining user experience in an EDPCG framework— namely, subjective, objective, or game-based. In the subjective approach, the user gives feedback about their experience, which might be subjectively biased and/or intrusive during the session. The game-based approach assumes that the users' interaction and performance in the game represents their cognitive state. However, these parameters are a low-resolution model of the players' experience and are not ideal for exposure therapy. The objective approach attempts to indirectly model the user's emotional state through their physiological response. Although this approach requires wearable sensors, it potentially fits in the exposure therapy context.

Related Work

Virtual Reality Exposure Therapy (VRET)

Virtual Reality-based therapy has been most successfully applied to exposure therapy, a treatment for anxiety disorders in which subjects are gradually exposed to anxiety-inducing stimuli in a safe and controlled environment to become less sensitive to the stimuli. Using VR therapy, subjects can also perform activities that may not be practical or safe in real life, i.e., someone with a fear of flying might take a virtual flight that provides the sights, sounds and smells of an airplane. VRET has been shown to be effective for treating different anxiety disorders (Maples-Keller et al. 2017); however, we focus on the studies that monitor physiological measures during VRET.

Multiple studies (Lister, Piercey, and Joordens 2010; Yadav et al. 2019; Kahlon, Lindner, and Nordgreen 2019) developed a virtual classroom with different audience reactions and audience sizes for individuals with fear of public speaking. The results showed an increase in skin conductance and heart rate while using VR and a significant decrease in pre-post treatment symptoms.

Côté and Bouchard (2005, 2009) developed a VR environment including spiders with different levels of difficulty (size of spiders and their walking pattern) for individuals with Arachnophobia. The results showed positive changes in physiological measures after treatment, indicating a decrease in anxiety.

Kritikos, Alevizopoulos, and Koutsouris (2021) developed an adaptive VR environment for Arachnophobia. They defined a handful of rules to change a spider's appearance and pattern of behaviour to induce the desired anxiety level in a subject. The level of anxiety is calculated based on the normalized electrodermal activity changes.

PCG for Rehabilitation

There are a handful of studies that implement PCG approaches for adaptive rehabilitation. Dimovska et al. (Dimovska et al. 2010) developed a ski-slalom game for physical rehabilitation, which places different gates procedurally according to the player's performance. Correa et al. (Correa et al. 2014) developed a self-adaptive first-person shooter game for amblyopia in which the game parameters were changed via PCG based on the patient's performance. Hocine et al. (Hocine et al. 2015) dynamically adjust the difficulty of a pointing task for upper limb rehabilitation according to the patient's motor ability and performance. Badia et al. (Badia et al. 2018) designed a VR labyrinth that promotes emotional self-awareness. They procedurally generate the maze and adapt the audio-visual elements to represent and induce emotional states. These studies applied a set of predefined rules to change the content, assuming the subjects were known ahead of time. Instead, we assume that the subjects are unknown and show different behaviours; therefore, game content needs to be generated and adapted dynamically based on each subject's needs.

Current Work

The main focus of this project is to develop a personalized virtual reality exposure therapy (VRET) system that adapts in real-time based on an individual's needs. Prior studies have shown the effectiveness of VRET for anxiety disorders and related disorders (Maples-Keller et al. 2017). The underlying assumption of this work is that personalized VRET is more effective in terms of treatment than a single VRET for all subjects.

Consequently, we propose a PCG-based framework for personalized VRET (Fig. 1). The framework has four main components. The *subject* interacts with a *VR environment* while physiological sensors collect data such as ECG, respiration rate, skin conductance, and temperature. The data is input to a *Stress Estimator* component, which predicts the player experience through our Player Experience Model (PEM), which includes stress. A *Procedural Content Generator* is passed the estimated player experience and adapts the *VR Environment* accordingly in order to maintain the desired PEM for VRET. The desired PEM for VRET is determined by a therapist or an expert, in order to maximize the effectiveness of therapy (not excessively stressful or tedious).

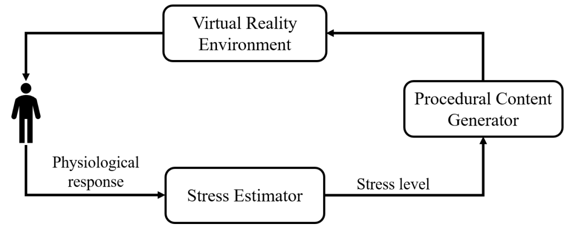

Figure 1: Proposed system framework

Based on the proposed system framework, our sub-objectives are as follows:

- Develop a system that takes as inputs the subject's physiological response and estimates their stress level. This system provides objective feedback about the user's experience, which can be used in the EDPCG framework. *In progress*
- Define an appropriate set of parameters for our system to adapt for different exposure therapy goals. For example, in fear of public speaking disorders, the size of the audience is an exposure parameter, but the environment's brightness is not relevant. *In progress*
- Develop a virtual reality environment that changes the exposure parameters automatically in real-time using PCG methods. It will also include a relaxing environment to measure the baseline physiological responses and calm the subjects whenever required. *In progress*
- Investigate the feasibility of using transfer learning methods to leverage the knowledge learned from one subject for another. The transferred knowledge might lead to significantly more rapid progress or improved performance in terms of finding the best exposure parameter values for new subjects. *Not started*
- Conduct two human subject studies, arachnophobia and fear of public speaking, and explore the effectiveness of the proposed EDPCG-based system for individuals with anxiety disorders. *Not started*

So far, we have developed a simple environment for arachnophobia as a case study. The environment includes a 3D spider with adaptive attributes, i.e., appearance and movement, based on a study by Linder et al. Lindner et al. (2019). This paper introduced seven spider attributes and asked spider-fearful individuals to self-rate each attribute's impact on their fear. The goal is to generate a spider with specific attributes that induces the desired stress level in the subject, e.g., moderate stress. We apply a Reinforcement Learning-based PCG (PCGRL) content generator to automatically adapt the spider according to the estimated stress level. Due to the ongoing pandemic, we utilized virtual subjects based on previous arachnophobia psychology research (Lindner et al. 2019) to compare our PCGRL algorithm with baseline algorithms, i.e., random, greedy, and genetic algorithms. The virtual subjects are 100 samples drawn from a PEM obtained from the study's findings, i.e., a probabilistic model with a normal distribution of the subjects' fear for each spider's attributes. Therefore, each virtual subject responds to each spider attribute differently. Fig. 2 shows an example of running our framework for a subject. The desired stress level in the figure is set to 7. The figure shows that the RL agent changed the spider with the attributes represented in the left side (small, far away from subject, without hair, brown color, without movement), to the attributes represented in the right side (large, very close to subject, with hair, black color, too much movement and human-like locomotion).

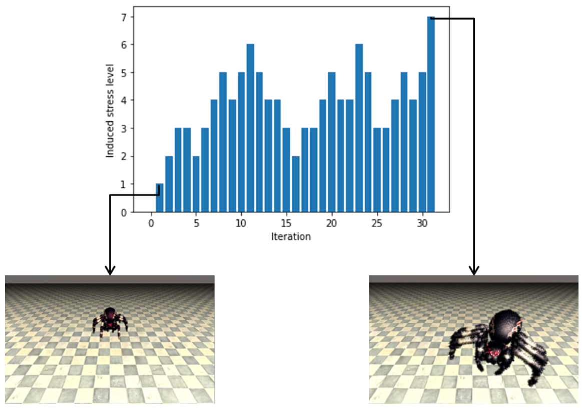

Figure 2: PCGRL results on finding the desired stress level (7) for a subject. The spiders presented in the left and right side induce stress levels equal to 1 and 7 respectively.

Our initial results are promising, as we found that our approach outperformed random, greedy, and genetic algorithm baselines.

Future Work

In the future, we plan to complete every in progress and not started task from the last section:

- First, we plan to develop a system that estimates the subject's stress levels based on physiological responses. We plan to train two machine learning algorithms, i.e., a Random Forest and an LSTM, on the existing datasets (Schmidt et al. 2018) to classify the subject's physiological response to "baseline" and "stress" states. We split the signals into predefined window sizes. The LSTM takes as input the time-series data within each window. In order to apply the Random Forest, we extract physiological features from each window, such as pulse rate. In order to identify the stress level, we assume that the membership probability of the "stress" state represents the corresponding stress level. For example, if a sample's membership probabilities are 0.27 and 0.73 for "baseline" and "stress" states, respectively, we assume a stress level equal to 0.7 (rounded to one decimal place).
- Second, we intend to find an appropriate set of parameters for specific exposure therapy goals using psychological literature and asking experts in the related fields. For example, Linder et al. (Lindner et al. 2019) found seven spiders' factors that usually scare subjects. These factors can then be used for arachnophobia exposure therapy. We need to define these parameters for fear of public speaking as well.
- Next, we use transfer learning to employ the information from previous subjects to a new subject. The idea is that because all the subjects suffer from the same disorder, we expect that they may show similar behaviours to some extent. Therefore, we plan on studying the differences between two PCGRL content generators; one utilizes the previous knowledge through transfer learning methods and the other starts without the prior knowledge.
- Finally, we intend to conduct a human-subject study. The study will start with a simple experiment that presents relaxing and stressful situations to observe how effective our VR environment is in terms of inducing stress in the subjects. We expect to witness significantly different physiological responses in these two situations. Then we compare our proposed framework versus non-adaptive environments in an arachnophobia test case using non-phobic individuals. We will compare our framework with other approaches in terms of different metrics that reflect exposure therapy effectiveness, such as quickly reaching and maintaining the desired stress level.

Conclusions

The purpose of this research is to present an EDPCG-based framework for exposure therapy, wherein it collects user experience based on objective measures. Therefore, accurately estimating the user's experience is critical, which affects the framework's performance directly. Building upon this, an initial challenge is to find the optimal number and types of sensors to measure physiological responses, which is a trade-off between intrusiveness and cost on one hand and accuracy on the other. Secondly, another challenge is to evaluate stress level as a multi-classification problem instead of a binary classification (with/without stress). Studying the trade-off between the granularity of the multi-classification problem (number of classes) and the model's accuracy is also important. Finally, we are required to evaluate our framework on real subjects. If it is feasible in terms of time and difficulty, we are interested in utilizing transfer learning methods to adapt the learned knowledge from one subject to another.

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