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Designing a Smart Virtual Environment for Autism Spectrum Disorder Detection

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***Abstract*—Emotional intelligence is not only a social skill for human beings, but also a challenging research topic in human-computer interaction related to the ability to recognize particular emotional patterns of humans by machines. Studies have shown that virtual reality (VR) can trigger stronger and more specific emotional reactivity in users than other visual/audio media. Children with autism spectrum disorder (ASD) usually suffer from social impairments, such as challenges in emotion perception and emotion expression. A smart VR eHealth system that carefully triggers specific emotional reactions and detects the patterns in children with ASD can help with early screening, intervention, and emotional regulation. This paper proposes a VR gaming system that makes use of psychophysiological sensor signals, in-game performance and responses, stressor mini-games to detect different emotional reactivity patterns, and dynamically changes the game scene according to the current emotional status. This is a framework of a long-term study, where the ultimate goal is to develop a VR system with real-time feedback to assist early screening and diagnosis of ASD.**

I. Introduction

In modern society, the emerging of Smart City and Internet of Things has been introduced with all kinds of technologies to increase the quality of lives [1], [2]. People who are physically or mentally challenged should not be left behind. In fact, smart eHealth is one of the important component for the smart world [3], [4], especially for early detection and self screening that could detect certain abnormality and provide suggestions for further professional consultation.

Autism Spectrum disorder (ASD) is a developmental disorder that affects communication and behavior [5]. Symptoms of ASD include difficulties with social communication and interaction, restricted interests, and repetitive behaviors. The traditional way of diagnosing ASD is through checking symptoms described by the patients against the criteria such as the Diagnostic and Statistical Manual of Mental Disorders and Gillian Autism Rating Scale [6]. The financial burden of raising a child with ASD is a challenge for the family. It is estimated that the total additional cost for families with ASD patients in the United States to be around \$11.5 billion – \$60.9 billion (2011 US dollars) [7]. Research has also shown that early intervention services in ASD can significantly enhance the child's development [8] and relieve the financial burden. Children with ASD are often afraid of interacting with real human beings, but rather feel more comfortable interacting with robots. Serious games that aim to effectively identify the ASD symptoms and detect potential symptoms in a relaxed and non-intrusive form can benefit this group.

Head-mounted virtual reality (VR) technology has been rapidly evolved in the past decade, making it a hot trend not only in entertainment but also in smart healthcare research [9]. VR provides a fully immersive experience and can meet the high requirement of controlled environment [10]. The precisely controlled environment can ensure safety and allows monitoring and intervening at any time if necessary. The possibility of triggering stronger and more specific emotional reactivity in a safer environment [11] has motivated the interest to use VR as a therapeutic intervention for individuals with mental disorders such as depression. However, using VR as diagnosing tool for mental disorders has not been thoroughly investigated yet.

In our current research, we propose an affective VR system that induces emotions and then analyzes emotional reactivity to the specific stimuli from the users. By instilling a sense of presence in the users through immersion and interaction, the system can impact current user emotions. Based on our previous research results [12], the emotional statuses will be different between the ASD groups and the typically developed (TD) control group. Distinguishing the patterns may give us evidence for early screening on the mental disorders related to a deficit in social and emotional competencies, including but not limited to ASD.

A study plan has been designed, and a few preliminary experiment sessions have been conducted. Surveys show that the VR scenes can trigger different emotional reactions as expected and participants were comfortable interacting with the virtual environment. The recorded signals show that participants actively responded to these emotions. The ongoing research project is believed to bring up creative and non-intrusive diagnostic and intervention methods that will benefit the mental development healthcare field.

II. Related Work

The following section contains a review of existing research on the use of virtual reality in the treatment of mental disorders. The section also contains research on

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mental disorders and utilizing VR to induce emotional responses.

A. Technologies for ASD

Applications of VR-based system recognition may significantly improve the effectiveness of delivering interventions for individuals with ASD. A review of "safety and usability of VR for children with ASD" [13] indicates that there is a gap in understanding how VR environments are experienced by individuals with ASD even though VR systems have high desirability features such as authenticity, realism, and ecological validity of interventions. Video games with biofeedback have been used as a training method for a few mental disorders [14]. At present, there are no reports showing that VR has been used in the diagnosis process of mental disorders, especially a VR application dedicated to assessing the user's emotional reactivity. Our research aims to provide a dynamic approach to assisting the early screen or detecting mental disorders with emotion impairments, compared to answering fixed questionnaires or traditional face-to-face interviews with professionals.

B. Emotional Recognition for Detection of ASD

Several studies have been launched to determine the feasibility in which desired emotional reactions could be induced in humans, with varying methodologies. Traditional methods such as written and video/audio media have successfully induced different emotional responses. Modern techniques involve utilizing VR and the concept of presence to elicit targeted emotions [11]. Furthermore, because of the better sense of immersion and exposure, VR has become a prevalent medium to combat mental illness, such as anxiety or phobia. Riva et al. [15] created a VR system used to induce a sense of presence in individuals suffering from an anxiety-induced overeating disorder. The results showed a significant correlation between the sense of presence and the user's emotional state. Herrero et al. [16] utilized presence in order to instill positive emotions in subjects suffering from fibromyalgia in order to combat their chronic pain. The study by Freeman et al. [17] describes a system that makes use of the sense of presence in order to help subjects overcome acrophobia, the fear of heights.

C. Affective Gaming using VR

Affective computing is an emerging technology introduced by Picard [18] in the HCI field. It combines multidisciplinary methodologies not only in the computer science field, but also in engineering, psychiatry, sociology, cognitive science, psychophysiology, and more. It aims to simulate the human ability of emotional perception, interpretation, expression, and process in machines. In the recent decade, researchers started to design games considering interactions with user emotions. Designing interactive games responsive to user emotions improves their effectiveness and user acceptance. With feedback on user emotional states as an extra dimension of game feedback, games will surely provide different aspects of user experience and be more attractive. Another traditional way of evaluating the playability of a system is through user testing and feedback, usually involving interviews or surveys and bug reports. Although the self-report method is often subjective and hard to scale, it does reveal insights from the user side that might differ from game designers' original thoughts. Capturing the differences will give us the markers to identify ASD symptoms, and eventually lead to early screening or detection through machine learning algorithms. Affective computing technologies have shown promising intervention in Autism Spectrum disorders by using traditional therapy with adolescents, who are generally not comfortable engaging with real people.

We designed and developed a series of affective VR scenes that can elicit different emotional reactions in users. To our best knowledge, although numerous systems have been designed to induce emotion and have been used to treat mental disorders before, such as in [16], [17], [19], no VR system so far has been designed to dynamically adapt to user emotions and detect mental disorders. The demonstrative game prototype can also serve as an emotional intervention game for people, where it changes scenarios, tasks, backgrounds, and music according to user emotional reactions while requiring physical movements to achieve health goals.

III. Methodology

A closed-loop feedback system is designed to use affective VR game scenes to impact the user's emotional status, then detect the change of emotions using signals and behavioral analysis, send back as feedback, dynamically adjust the themes and difficulty levels of the virtual environments accordingly. In the current pilot study, we systematically developed an affective VR prototype and designed an experiment to collect data from different groups of participants. The data will be analyzed offline to learn the emotional patterns and differentiate the groups. The analysis results will serve as evidence for designing more in-depths affective game scenes that adapt dynamically to recognize possible emotional disorders.

A. Designing Framework

A closed-loop framework is shown in Figure 1. This closed-loop affective game system consists of three essential modules: affect modeling module, affect recognition module, and affect control module. The dashed line indicates the optional offline path that does not provide dynamic changes to the game scene according to the user's emotional status, but instead uses a random or predictive model for data collection purposes.

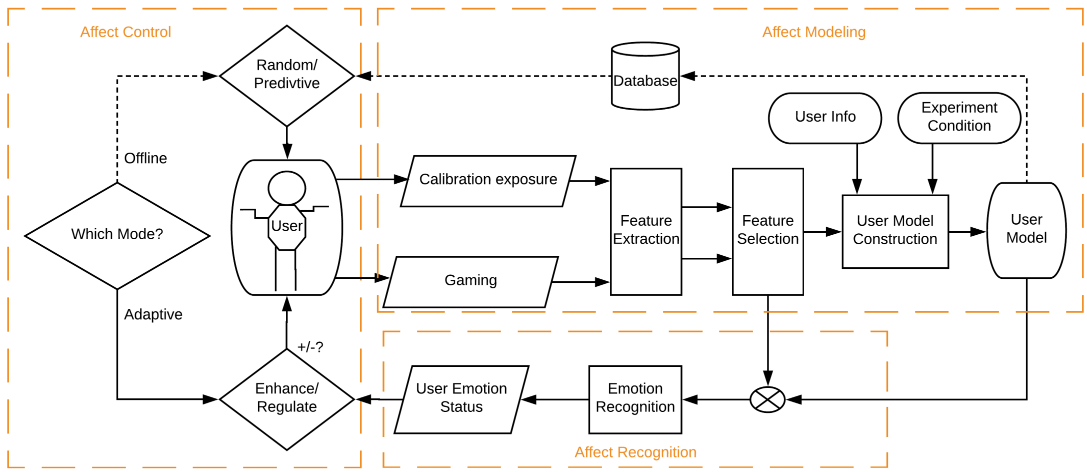

Fig. 1. A closed-loop affective game system.

1) Affect modeling module: The affect modeling module mainly collects user data from all measures and 400 extrapolating out to construct user models. Machine learning algorithms are used for training models and recognizing different emotional reactivity patterns with psychophysiological or behavior features.

2) Affect recognition module: This module is mainly applying the learned user model to recognize user emotional states. The results can either be sent off-line to improve the user model further if the off-line mode is selected or sent to generate a feedback game scenario for real-time adaptivity.

3) Affect control module: This module changes the environment according to user emotional states. The environment includes any individual or combined methods, such as visual exposure (picture, video, 3D, or VR), and audio exposure (affective sounds or music) to induce users' emotions.

B. Instruments

In order to demonstrate this interactive game framework, an interactive VR game prototype was developed, which consists of all essential modules described in previous chapters and sections. The system hardware includes an HTC Vive and a PC for hosting the game scenes and real-time signal monitoring. The device we used to monitor and record physiological signals is Empatica E4 [20]. It is a medical-grade wearable device that records and allows for real-time monitoring of physiological data gathered from the wearer. Embedded inside the wristband is a multitude of sensors that monitor heart rate, galvanic skin response (electrodermal activity), and other forms of physiological data. The data can be tracked and monitored in real-time during the experiment sessions with the E4 Realtime mobile application. Once a recording session is completed, the data is saved inside a cloud network for later analysis. The target VR platform is any headset devices that are compatible with the SteamVR toolkit.

C. Data Collection

The data is collected during the experiment is listed as follows:

1) Visual analogue scale (VAS) [21]: All participants will complete the VAS survey before and after the experiment in order to assess their emotional states. Participants are asked how they felt before the experiment and how they felt under specific stimuli after the experiment. Participants rate their emotional experiences on a scale from 1 to 7, with number one being equivalent to "Strong disagree" and number seven equivalent to "Strongly agree".

2) In-game performance: The reaction times for performing specific tasks are recorded. The length of completing each session and the user's in-game self-reporting mood status are recorded as well. They will be analyzed to assess the performance of individuals under the impact of different emotions.

3) Galvanic skin response (GSR): The participants' galvanic skin responses are monitored and recorded in all three simulations. GSR is commonly used to measure the Autonomic Nervous System activity. It is believed to be not under conscious control [22] and is highly related to emotional arousal.

4) Heart rate : The participants' heart rates are monitored and recorded throughout all three simulations. Heart rate is also an important indicator of emotional reactions. Its derived dependent measurements, known as heart rate variability, have also been proved to be related to emotional reactions [23], including derived variables in both time domain and frequency domain.

D. VR Application Design

In the application prototype, one entry tutorial, three main emotional-laden VR scenes, one mental stressor mini-game, and one physical activity scene were designed and implemented. It starts with an entry tutorial level, followed by three sessions separated by a short break, each testing the user's mental stress under different emotional impact by a memory mini-game, ending with the same physical exercise "reset" scene. The three emotional-laden VR scenes are placed in the same level map layout with the same routes to go through, the same non-player characters (NPCs) to interact with. The different emotional tones of the scenes are carefully embedded with the variation of the background sound, the weather, the interactions, and signs to read. This systematic design reduces the potentially different arousal for VR scenes, especially from the participants who have never experienced VR before. More details are explained in the next section.

1) System architecture: The application features a number of mechanics. These include movement, interaction, dialogue, mood reporting, block matching, aiming, and shooting among others. The movement is used primarily as a means of traversing the town, allowing the player the freedom to explore and find the game's many interactions. This, paired with the interactions themselves and the accompanying dialogue the player engages in, gives birth to the dynamic of exploration, engrossing the player in each day's given emotional stimuli. In addition to physiological signal monitoring, the game features a means of self-reporting of the player's mood that can be performed at any time to gather insight on the efficacy of individual interactions.

2) Gameplay Design: The user can move about freely with directional controls by teleporting. Upon finding something or someone with which they can interact, a prompt will appear that lists how they can respond. This will impact a hidden mood meter that represents the player's current emotional state.

In the school portions of the game, the user can move within the classroom to one of several stations (framed as in-game "exams"). Interacting with these stations will begin one of the mini-games.

At any moment, the player can toggle on the mood self-reporting interface, to choose whether they are feeling neutral, negative, or positive. The recorded physiological signals and self-reporting mood data can then be compared to the "expected" mood revealed at the end of the town portion. The analysis of the data will be used to evaluate how effective the tests are and what might more strongly affect players' emotions.

IV. Implementations

All the game scenes are implemented with a head-mounted VR device. The game is fully immersive and interactive.

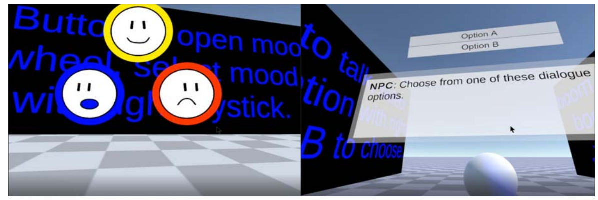

Fig. 2. Tutorial screenshots. Mood self-reporting UI (left), dialogue choice UI (right).

A. Tutorial Level

The tutorial level is designed to let users get used to VR and practice the essential gameplay of the system. Two screenshots of different UI practices are shown in Figure 2. This level is not timed, so that the participant may move freely and take as much time in practicing game controls as needed before they are ready to start. There are instructions in the middle of the screen on how to control their character. Once the participant moves forward to trigger the "Start" sign, the scene will transition into the neutral level.

B. Three In-game Day Levels

For all in-game days, the players will have the same tasks: walking to the school and taking school "exams" (mini-games) at school.

During the town portions of the game, the user's only objective is to walk to school. Depending on the day, there will be several events that the player will encounter that they must interact with; only after completing these interactions can the player move on to the school portion.

In the school portions of the game, the player completes a series of mini-games and is given feedback on their performance. The goal of these portions is to determine if the user's score differs between school days under different emotional impacts. After completing all of the mini-games for the day, the player moves on to the next day.

1) Neutral day: The neutral scene is designed as a baseline for VR arousal. Two screenshots of a neutral day are shown in Figure 3. It has the common essential elements of the virtual environment across the three scenes, but with minimum interactions and stimuli. The user starts from waking up at home, with a single path to walk to school. Neutral messages carefully chosen from the Velten technique are written on signs alongside the pathway. There are limited indications on the weather, no sound effects, and no other interactions are implemented in this scene.

2) Negative day: The negative scene (Figure 4) is designed to stimulate a negative day. In order to accomplish this, changes were made to make the atmosphere sadder and more depressing. Among these are that the thunderclouds in the sky and trees with bare trunks. Background sound

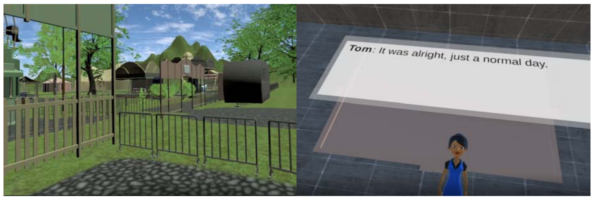

Fig. 3. Neutral scenery (left), neutral dialogue (right).

Fig. 4. Negative scenery (left), Negative sign (right).

Fig. 5. Positive scenery (left), positive sign (right).

was employed to play thundering noise in order to make the clouds appear more ominous. The park was designed in all means to be abandoned, without live creatures. The signs located along the path contain messages designed to suggest sadness and sorrow.

3) Positive day: The positive scene (Figure 5) is designed to induce a positive emotional response in the user. Changes were made to the environment to accomplish this. Among these are that the sky contains a yellowish hue to convey a feeling of warmth. Background sound includes the sounds of birds chirping. Cats and dogs were walking and playing to make the pathway feel alive. The participant may choose to pet the animals or ignore them as they prefer. The signs along the path contain positive messages designed to make the user feel encouraged and confident.

C. Mental stressor mini-game

In this level, the user must recognize and remember the patterns of colored blocks presented to them and manipulate the blocks in front of them to match. There are no winning or losing criteria for the mini-game. The participant starts with two colored blocks, and the number of blocks with different colors goes up until he/she fails to remember the correct location. The time is recorded and the number of successful trials is used to compare the performance under different emotional impacts. A screenshot is shown in Figure 6 on the left.

Fig. 6. Mental stressor mini-game (left), physical exercise mini-game (right).

D. Physical exercise (reset) mini-game

At the end of each in-game day, the user is requested to perform a mini-game as a "reset" to physiological signals: a simple physical challenge where the player must finish a certain number of jumping jacks. This scene is designed to utilize simple physical exercise to bring up the physiological arousals, in order to "reset" the possible impact of the affective VR scenes, so that the user can enter the next session after a short break, without the retention of the emotional levels from the previous session. After this reset, the participant can take a short break until he/she feels ready for the next scene. A screenshot is shown in Figure 6 on the right.

E. Procedure

The participants in the ASD group are set to be recruited within diagnosed high-functioning autistic children through a collaborative local school for special needs. The control group will be recruited through another local school with TD kids in the same age range. The preliminary experiment is planned to start with ten children in each group.

The experiment is designed in the following steps:

Firstly, a researcher instructs and explains the consent form. After giving written consent, the participant will take a pre-test VAS survey, providing answers about their current mood as well as emotional status in the recent two weeks. The E4 wristband will then be attached to the participant's preferred side of the wrist.

After the pre-test survey, the researcher helps the participant to put on the headset. Then the touch controllers are handed over to the participant. The participant then adjusts and then starts the game. There are two monitors used during the game sessions. One screen is used to stream the VR scenes that the participant is experiencing, and the other is used to monitor the real-time wristband readings on GSR and heart rate. The participant will also self-report the mood in the game using the toggled interface at any time.

Three in-game days are separated as three continuous sessions. The participant may take as much time as needed to relax and recover until he/ she is ready for the next session. The time to complete each and all sessions is recorded, and the participant will be assisted to take off the headset.

After all three sessions are completed, the participant will be given the post-test VAS survey to complete. The maximum time commitment per participant is one hour, including all consent, survey, game sessions and break time. Generally each in-game day takes only around five minutes.

V. Measurement

As mentioned in the Data Collection Section, VAS, in-game performance, and self-reported mood status, GSR, and heart rate are collected and analyzed. The hypothesis hinges that individuals in the ASD group will show stronger arousal but less specific valence to each scene than the TD group. Moreover, the tendency or precepted emotions in each group will be different. This will serve as evidence for a more refined design of specific virtual events to build customizable scenes for further intervention purposes.

1) VAS score data: The pre- and post- VAS survey data determine the effectiveness of using VR as a tool to detect and screen developmental disorders. It also gives information on the participants before and after session presence and attentiveness, as well as some real time behavior recording. The VAS score from the four different stages, i.e, baseline, negative, neutral, and positive moods, are categorized and compared. The results between the controlled and diagnosed group will be by mean, standard deviation, and pairwise t-test of the scores using standard statistical analysis.

2) Reaction time: Reaction time will be used to quantitatively analyze the time taken to complete the different dynamic moods, physical exercises, and mental stressor. The amount of time that the participants take to complete the "reset" physical exercise after each session are also included. Statistical analysis will be conducted using functions such as mean, pairwise T-test, and standard deviation of the acquired data.

3) User emotional model: The GSR and heart rate will be analyzed with classic machine learning methods. Emotional valence labels will be made from the VAS score associated with the participant. Combining with the expectations of the original design of the scene, the user emotion model will be derived. The assumption is that each individual with high-functioning ASD will reveal different patterns than the control group; thus, a more customizable user model will be needed for further investigation.

VI. Discussion and Conclusion

In the pre-run experiment before the pandemic of COVID-19, participants included one high-functioning autistic, and two TD individuals. The post-survey indicated an increased sense of sadness generated by the negative VR scene and an increased sense of happiness and relaxation caused by the positive VR scene. The preliminary data also shows parasympathetic activation (relaxation) is experienced during the positive game scene. The high-functioning autistic reported the whole session is with an acceptable length and activity strength.

The current study belongs to an ongoing long-term research project. At present, we developed an affective VR system capable of inducing different emotional reactions in our users by utilizing the sense of presence. The results via preliminary surveys justified that we have accomplished this objective. An empirical study has been planned in the coming fall of this year, and more data will be collected from a larger group of participants. The analysis results will lead to building a customizable system that learns from each individual with ASD, and adaptively change game scenes to assess the user's emotional status. This will lead to the detection of unusual patterns of emotional impairment. It is expected that the results of this project will lay the foundation for future smart eHealth diagnostic approaches for mental disorders related to emotional impairments.

Privacy protection is an important section for all healthcare-related projects due to the severe privacy leakage risks [24], [25]. Therefore, we will apply privacy protection algorithms to this work.

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