Sensor-Based Virtual Reality for Clinical Decision Support in the Assessment of Mental Disorders

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***Abstract*— Recent reports show that 1 in 4 families has at least one member with a mental disorder. In the current practice, most diagnosis methods in psychiatry are based on clinical interviews and questionnaires, which are subjective and can lead to recalls and interviewer biases. In the healthcare context, Virtual Reality (VR) has shown a strong potential to improve decision making and help patients to better connect with reality, cope with pain, and overcome mental disorders such as anxiety and depression. This study integrates sensing technology (i.e., eye tracking) with a VR simulation of healthcare environments to improve the clinical decision-support system for diagnosis and assessment of mental disorders. Traditional scenario-based patient simulations are used as a basis for the development of VR modules. Data collected via the eye-tracking sensing technology are utilized to develop analytical models for predicting the risk of mental illness. Moreover, artificial intelligence (AI) tools for VR-based healthcare training help medical students learn faster and make smarter decisions. This research helps contribute to improved population health by developing new methods for promoting health and effectively predicting and treating mental disorders.**

Keywords—mental disorders, virtual reality, eye tracking, clinical decision making, metacognitive

I. Introduction

According to the World Health Organization (WHO), 35 percent to 85 percent of mental health conditions go undetected and undiagnosed [1]. Effective diagnosis is the first step that is indispensable to treating mental conditions. Traditional tools (e.g., interviews and cognitive tests) used for the assessment of mental disorders are subjective and fraught with complications and subtleties [2]. Moreover, mental disorders are often unrecognized and undertreated. Inaccurate assessment is one of the important barriers to improve the quality of care [3]. Virtual Reality (VR) technology is more accurate in diagnosing mental disorders than traditional "gold-standard" cognitive tests [1]. VR provides a unique opportunity for healthcare training and treatment of mental disorders in a safe, controlled environment. However, more research into what makes VR therapies effective is urgently needed. Rapid advances of VR technology have fueled increasing interests and steady growth in healthcare applications. For example, VR is conducive to improve medical training for decision making, and help patients to cope with pain, overcome anxiety and depression. VR has been used to assess and treat a wide variety of medical, surgical, psychiatric, and neurocognitive conditions as well as to enhance the effects of conventional therapies [4]. VR enables longer training sessions and brings a reduction in overall hospitalization time [5]. However, most of existing works in this field are in the form of feasibility studies and pilot trials [6]. The integration of eye-tracking with VR can provide insights about an individual's subconscious reactions when interacting with the VR environment. In combination, the two techniques allow unprecedented monitoring and control of human behavior in semi-realistic conditions [7].

This study discusses the development of a sensor-based VR screening tool for mental disorders. The VR environment consists of a virtual medical clinic where patients can navigate through to complete mental health assessment tasks that are developed to mimic common mental health simulations conducted in the nursing labs. Eye-tracking sensing technology is used to collect non-self report data from the VR simulations to understand abnormalities in eye movements correlated with mental health disorders. The study also develops models for effective metacognitive strategies. The AI models utilize user input and the data collected via sensing technology to provide proper metacognitive interventions that address mental disorders. Metacognitive interventions are effective in alleviating symptom severity in mental disorders [8].

II. Research Background

The study of VR applications in healthcare has been discussed by multiple researchers. Carl et al. provided an examination and comparison of 30 published papers for Virtual Reality Exposure Therapy (VRET), including fourteen for specific phobias, eight for social anxiety disorder (SAD), five for post-traumatic stress disorder (PTSD), and three for panic disorders [9]. The random-effects analysis estimated that VRET had a larger effect than waitlist controls, and a moderate to large effect compared to

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psychological controls, while having no significant difference compared to in-vivo conditions [9]. A study presented a VR enabled program for helping autistic children enhance their emotional and social adaptation skills using six learning scenarios. Results showed significant improvement in emotion expression, regulation and social-emotional reciprocity in the primary measures, but not on other secondary measures [10]. Further, a comparison study is performed to benchmark the efficacy between a combination of virtual reality exposure, cognitive behavioral therapy (VRET), and traditional cognitive-behavioral therapy (CBT) in reducing symptoms in patients with agoraphobia. Results showed both therapies were statistically effective during post-treatment and a six month follow up though the VRET group showed more clinical improvements than the CBT group [11]. VR tools are also used to help schizophrenic patients learn social skills and improve their social cognition was discussed in [12]. The analysis of variance (ANOVA) results of repeated measures revealed significant improvement in symptoms and other gains, those of which are also maintained at the four-month follow up [12].

In addition, VRET was compared with the efficacy of Trauma Management Therapy (TMT) in a randomized, controlled trial of 92 Iraq and Afghanistan veterans and active military personnel with combat-related PTSD [13]. VRET resulted in significant decreases on the Clinical and Military PTSD scales; TMT resulted in more significant decreases in social isolation; both resulted in decreases in anger and depression; and neither improved sleep, thus leading to the conclusion that VRET alone cannot produce optimal treatment results [13]. Lotan et al. also conducted a study on the effectiveness to use a VR based exercise program for adults with severe intellectual and developmental disabilities (IDD).

Through the monitoring of heart rates, results showed a significant reduction in heart rate for the research group but no change in the comparison group. The experimental results are not strong enough to say the program improved an IDD patient's physical fitness [14]. A study examined the effectiveness of VR in enhancing the motivation of individuals with mental disabilities to partake in rehabilitation. Through a comparison of VR and traditional roleplaying, results showed the VR group demonstrating greater interest in social skills training, leading to greater improvements in conversational skills and assertiveness, but less in nonverbal skills [15]. A study showed that patients are more likely to disclose mood and anxiety based issues to a virtual agent than a human therapist [16]. Another study integrated eye tracking with the memory sensitive, visual paired-comparison test for the analysis of the length of time a person would look at a new photo and then make comparisons to one they have already been exposed to [17].

Given these evidences from previous studies that show the effectiveness of VR in assessment and treatment of mental and intellectual disabilities, this study further develops a sensor-based VR environment for the assessment of mental disorders.

III. SENSING-BASED VIRTUAL REALITY ENVIRONMENT

In this study, we utilize VR and eye-tracking technologies to develop a sensor-based approach for the diagnosis and assessment of mental disorders. The VR environment was developed using the Unreal Engine (www.unrealengine.com) and HTC Vive headsets. The team first watched and documented mental health simulations in the nursing labs and then used that as the basis for developing the VR environment. Fig. 1 shows a student exploring the VR environment.

Fig. 1. A student exploring the virtual reality environment

The VR environment consists of a virtual medical clinic where patients can navigate through and then complete mental health assessment tasks. These tasks are developed to mimic the mental health simulations. Fig. 2 shows the patient waiting room in the VR clinic.

Figure 2. Waiting room in the mental health clinic

In the current phase of the study, we develop a simulation specific to Schizophrenia - a serious mental disorder that causes people to interpret reality abnormally. The simulation includes an audio file mimicking voices heard by those who have Schizophrenia. Users are instructed to listen to audio through headphones and write down their thoughts while doing so. Users are also asked to complete questionnaires while audio is still playing. In addition, they are asked to solve word puzzles and test reading comprehension. In Fig. 3, the small red button on the wall is used to turn the audio file on and off. The participants use the whiteboards to complete the questionnaires and solve the puzzles. They can also write down on the board using a virtual marker.

Fig. 3. A snapshot from the VR environment showing the doctor, audio button, and boards that enable users to write, draw, and answer survey questions

We further developed identical rooms in the VR clinic with some minor differences and the user will navigate through both rooms and identify the differences. For example, Fig. 4 shows two identical rooms with one minor difference; there is a white vase on the table in the first room. During this step of the simulation, eye-tracking data are collected as in-process observations of users' behaviors.

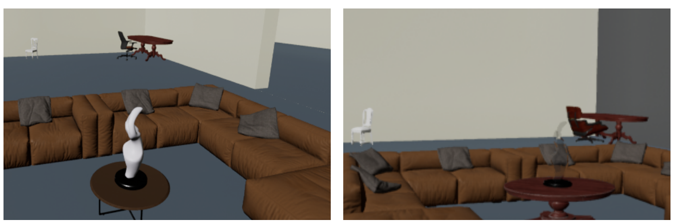

Fig. 4. Identical VR rooms with one minor difference

A. *Assessment of Mental Disorders*

To achieve a quantitative measure of mental disorders, we combine signal detection theory and conflict and error algorithms to measure the metacognitive performance based on the following equation:

$$\xi = \sum_{i=1}^{T}\left[\sigma\Phi^{-1}(Y_i) - \left(\Phi^{-1}(C_i) + \Phi^{-1}(E_i) + \Phi^{-1}((C\&E)_i)\right)\right] \quad (1)$$

where ξ is the metacognitive awareness measure, T is the set of tasks, Φ^{-1} is the inverse normal distribution (we assume the behavior is normally distributed), Y is the correct task execution, C is the conflict (performing a task different from what the person is thinking measured by eye tracking), and E is the error (performing a wrong task). The conflicts and errors are defined in reference to the average performance of individuals without mental disorders. Lower values for ξ indicate that the user has more errors and conflicts than correct tasks while performing the VR simulation, which can be an indication of mental disorders [18-19].

B. *Healthcare Training*

The full version of the VR simulation environment has two modes, i.e., a patient mode and a training mode. The patient mode includes a set of tasks to be completed by the user for the assessment of their mental disorders. The training mode focuses on symptom identification, which provides decision support to healthcare personnel for the differentiation of disorders.

Depression disorder results in a loss in interests and/or persistent sadness. Anxiety disorder causes a user experiencing panic or distress in response to a scenario. Depression and anxiety disorders have an association which each other and can be hard to distinguish [20]. Schizophrenia is characterized by the National Institute of Mental Health as having altered perceptions, abnormal thinking, and odd behaviors; a schizophrenic may also experience negative and cognitive symptoms [21].

An AI-assisted doctor model is developed to ask questions and accept a text-based form of user input related to depression, anxiety, and Schizophrenia. These inputs are processed to compare symptoms the patient is experiencing to the respective disorder.

C. *Preliminary Results and Analysis*

We collect data from the VR environment using eye tracking. We use a virtual reality headset outfitted with an eye-tracker within the mark. The eye-tracking data include: (1) Gaze Origin: the origin of a ray cast from the eye, (2) Gaze Direction: a 3D vector that shows what direction the wearer is looking, (3) Fixation point: the location of where the eyes converge, (4) and Confidence Value: a number [0, 1] that denotes the reliability of the sensor. These as well as the user's location are written to a CSV file for triangulation. The resulting data will then be compared to a video of the user in physical space. Because we have not recruited any participants at this phase of the study, we generated simulated data to show how metacognitive measure is used to assess mental disorders. Two simulated datasets for ten tasks are generated; one dataset for a person without mental disorders and another for a person with mental disorders. Fig. 5 shows the performance of a person without mental disorders and Fig. 6 shows the performance of a person with mental disorders. Be referencing to equation (1), the normal person should have more correct tasks than errors and conflicts. The person with mental disorders will have less correct tasks than errors and conflicts.

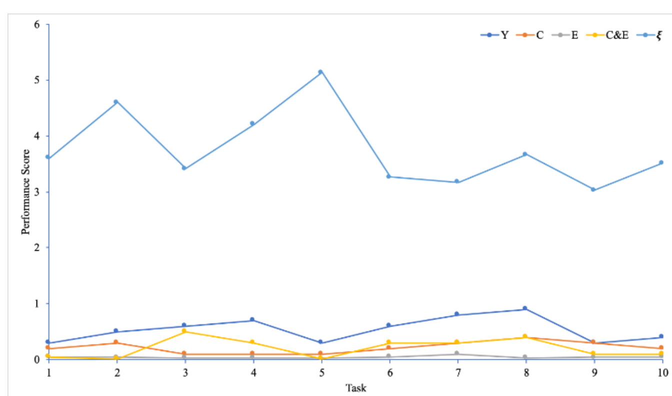

Fig. 5. The performance variations of a person without mental disorders

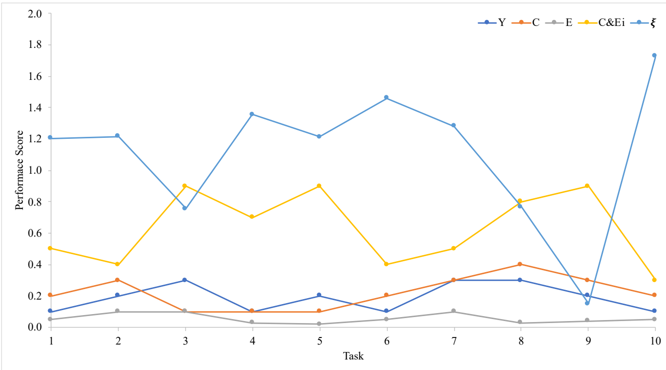

Fig. 6. The performance variations of a person with mental disorders

IV. Conclusions and Future Work

In this study, we develop a VR simulation environment for the assessment of mental disorders and leverage sensing technology (i.e., eye tracking) for data collection and monitoring of participants' behavior. Our goal is to improve clinical judgment and treatment of mental disorders (e.g., anxiety, depression, and schizophrenia) by improving metacognitive skills.

The future study will continue to improve the VR simulation environment by adding more tasks and considering different types of mental disorders. We will also run participants and benchmark the VR simulation with traditional patient simulations and mental health screening tools. VR-based metacognitive interventions for treating patients with mental disorders will also be developed.

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