A Virtual Reality-based Psychological Health Assessment System

Jiading Qin
Shandong Vocational College of Science and Technology, Weifang, China

Abstract: Traditional assessment systems struggle to create virtual testing environments, resulting in poor effectiveness of psychological health assessments. Therefore, a psychological health assessment system based on virtual reality technology is designed. This system utilizes hardware devices such as sensors, data gloves, and head-mounted displays to collect psychological health data from assessors. Through the integration of image modules, interactive controls, VC++, and OpenGL, a virtual reality psychological health assessment environment is constructed to enhance assessment effectiveness. The assessment model is built using the Analytic Hierarchy Process to complete psychological health assessments. Experimental results demonstrate that the ecological validity of the system is close to 100%, and assessors' sense of spatial presence and engagement percentage both exceed 95%, indicating good virtual reality simulation effects.

Keywords: Virtual Reality Technology; Head-Mounted Display; Analytic Hierarchy Process; Data Gloves; Assessment Model

1. Introduction

Psychological health assessment, characterized by processing assessor's psychological condition data through relevant means and analyzing the assessors' behaviors regarding personality, abilities, and other values based on the processed data, is a significant aspect of psychological evaluation. In today's society, there is an increasing emphasis on individuals' psychological well-being, with psychological health often included in routine medical check-ups. With advancements in technology, the technical sophistication of psychological health assessment methods has also increased.

Xu Yi et al. proposed a psychological health assessment system based on rough set theory, which obtains psychological status information through questionnaires, calculates psychological status influencing factors using rough set theory, and then extracts a set of psychological status evaluation criteria using decision tree algorithms to obtain psychological status detection results [1]. Li et al. developed a web-based psychological health assessment system using a B/S architecture. This system is designed with B/S software architecture, builds a student psychological health database based on SQL Server, and includes modules for remote counseling, self-diagnosis, on-site assessment, etc., to achieve the system's assessment functions [2]. In recent years, virtual reality technology has been applied in various fields. This technology constructs three-dimensional dynamic environments through computers, enabling the integration of information from multiple sources and providing assessors with an immersive experience during the assessment process, thereby enhancing the effectiveness of psychological health assessment [3,4]. This paper combines virtual reality technology to design a psychological health assessment system, aiming to better achieve psychological health assessment objectives.

2. System Design

2.1 Overall System Structure

The system integrates the OpenGL graphics function library with a display monitor [5]. It utilizes the client/server instruction model within this graphics function library and VC++ programming software to display information from interactive devices such as data gloves and head-mounted displays on the computer screen. The system framework is illustrated in Figure 1.

The psychological health assessment system mainly consists of hardware devices such as sensors, head-mounted displays, data gloves, and software modules including image processing, interactive control, and evaluation [6]. Utilizing data gloves, head-mounted displays, and other equipment, relevant psychological health data of assessors are collected. These data are then connected to a virtual reality psychological health assessment environment constructed using VC++ and OpenGL through the display interface [7]. The image processing module, employing OpenGL and 3DMAX software, establishes character and environmental models, representing a crucial application of virtual reality technology. The interactive control module enables functions such as collision perception and voice recognition for assessors, detecting actions like exertion and speech during the assessment process. The behavioral prompting module is responsible for providing assessors with verbal, textual, or visual prompts [8]. For instance, if assessors exhibit signs of agitation or distress during the assessment, this module can help them regain stability through soothing verbal cues or comforting visuals. Lastly, the evaluation module employs the Analytic Hierarchy Process to assess the psychological health data of assessors, thereby completing the psychological health assessment process.

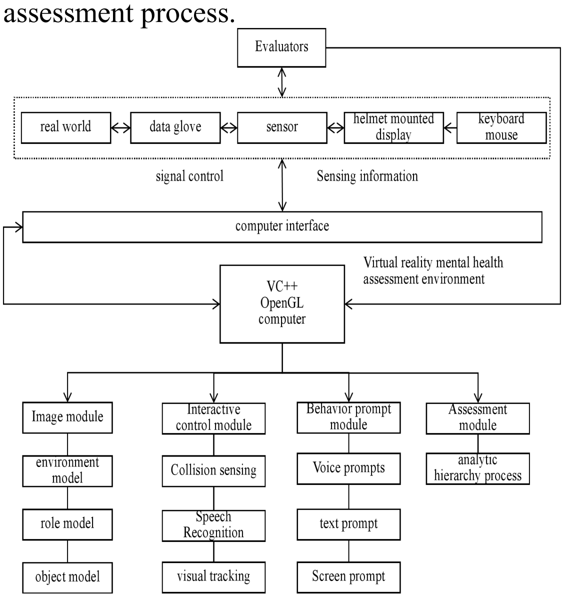

Figure 1. Structure Diagram of Mental Health Status Assessment System

2.2 System Hardware Composition

2.2.1 Helmet Display Integrated Design

The helmet display, also known as the head-mounted display (HMD), is an image display and observation device that outputs virtual reality viewing effects in a wearable manner for the user. The system's helmet display consists of an ARM processing submodule and a FPGA programmable logic submodule, as specifically illustrated in Figure 2.

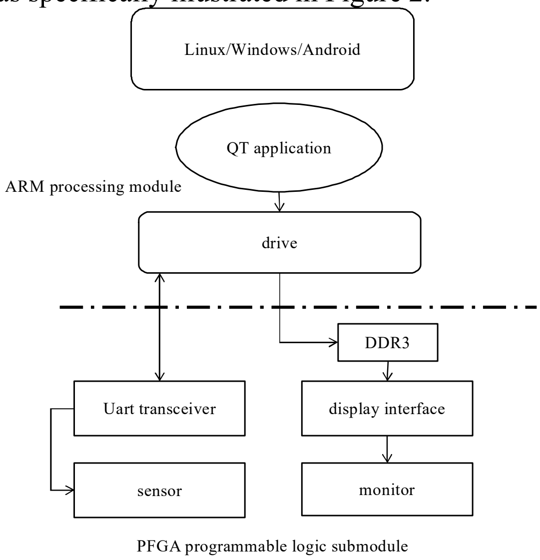

Figure 2. The Helmet Display Forms a Schematic Diagram

The ARM processing submodule can implement changes in user demand configurations by embedding the driver within the operating system and running QT program files, displaying the helmet information interface on the monitor [9]. The FPGA programmable logic submodule utilizes DDR3 memory to connect the helmet display interface with the monitor, achieving helmet display functionality. It connects to the sensor via the AXI bus protocol by linking with an asynchronous transceiver, thereby transferring data related to the psychological health of the evaluator to the computer interface.

2.2.2 Data Glove Mechanical Structure

The data glove's mechanical structure in the system utilizes a tri-link design. When the evaluator wears the data glove, it forms a closed four-bar linkage with their fingers.

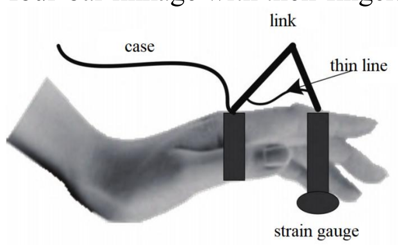

Figure 3. Feedback Structure of Data Glove

The fine wire is placed inside the connecting rod, and when the wire is subjected to force, this force is transmitted to the evaluator's fingers through the wire, utilizing finger joint rotation to create a sense of force. The mechanical force feedback structure of the data glove is shown in Figure 3.

The hub of the miniature motor is connected to the sleeve by a fine wire, utilizing the rotation of the hub to adjust the tightness of the wire. The data glove uses the force feedback structure depicted in Figure 3 to enclose the force motion range, allowing for more precise determination and transmission of motion trajectories, and the device has strong universality. To prevent malfunction of the miniature motor, a steel strip and strain gauge are placed at the finger positions. When the palm remains extended, a physical brake is formed, thereby ensuring the data glove system has a higher safety level.

2.3 System Software Design

2.3.1 Establishment of Evaluation Indicator System

The system evaluation module employs the Analytic Hierarchy Process (AHP) to assess mental health conditions. At the onset of the evaluation, it is necessary to establish an indicator system for mental health status.

Based on data collected from devices such as the helmet display and data gloves concerning the evaluator's mental health condition, an evaluation indicator system for mental health status is established, as shown in Table 1.

Table 1. Psychological Health Status Evaluation Index System

First level indicator	Secondary indicators	Level three indicators
Mental health assessment index system	social factors	Views on social climate
		attitude towards speech
		values
	Family Factors	Family conditions
		Education level
		family emotional factors
	personal reason	communication situation
		Character composition
		Physical conditions

2.3.2 Evaluation of Psychological Health Status

Use the evaluation indicators established in the previous section to build an evaluation model. The model evaluation process is shown in Figure 4.

According to the rules of the mental health status, experts evaluate the psychological health data of the evaluation staff, and use the expert evaluation results to obtain the comprehensive results of the mental health status of the evaluation staff. Opinions have rationality and objectivity.

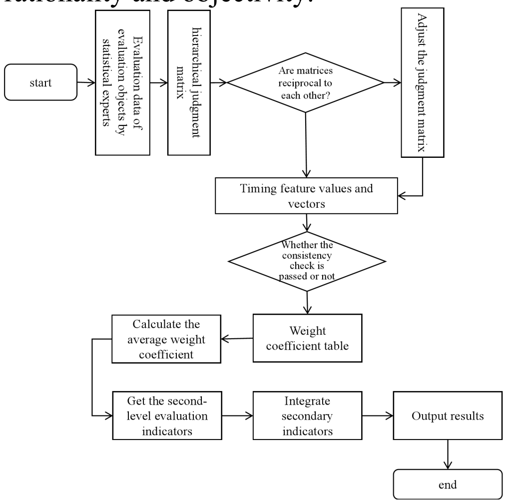

Figure 4. Evaluation Process

Assuming there are k experts, where C_i and g_i respectively represent any indicator and its corresponding weight, with i=1,2,…,k, then the weight calculation formula for mental health status indicators is as follows:

$$W_i = \sum_{i=1}^{k} \frac{g_i}{k} \tag{1}$$

Using formula (1), the weight coefficients of various indicators of mental health status can be obtained. The evaluation process of the fuzzy integration evaluation model is as follows:

Step 1: Construct a set of factors for mental health status, letting the third-level indicators within the mental health status indicator system be represented by $U_1, U_2, \ldots, U_4$.

Step 2: Construct an evaluation set, with the system in this paper using V={A, B, C, D} to represent the evaluation set.

Step 3: Construct an independent factor judgment matrix. Let the fuzzy subset of factor U_i be R_i, and obtain the membership degrees of each mental health status evaluation indicator through the judgment method of k experts. When there are k_ij experts whose judgment level for factor U_i is V_j, then the expression formula for the judgment matrix is as follows:

$$R = \left(\frac{k_{i1}}{k}, \frac{k_{i2}}{k}, \cdots, \frac{k_{im}}{k} \right) = \left(r_{i1}, r_{i2}, \cdots, r_{im} \right) \tag{2}$$

Step 4: Calculate the weight of each indicator, the formula of the weight collection is as follows:

$$W = \left(w_1, w_2, \cdots, w_n \right) \tag{3}$$

The important degree of the indicator weight is as follows:

$$\sum_{i=1}^{n} W_i = 1 \tag{4}$$

In the aforementioned formula, the importance of the i-th indicator's weight relative to other indicators is represented by W_i, and W_i is within the interval of 0 to 1.

Step 5: Implement a fuzzy conversion of the comprehensive evaluation results. Based on expert opinions and the maximum membership degree rule, use formula (2) to obtain the final evaluation result, thereby obtaining the evaluation results for the second-level indicators of mental health status, with its expression formula as follows:

$$B = WR = (w_1, w_2, \cdots, w_n)\begin{pmatrix} r_{11} & \cdots & ar_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} = (b_1, b_2, \cdots, b_n) \tag{5}$$

According to the results of the judgment standard processing formula (5), the number of evaluations of the secondary indicators is calculated using the function to calculate the number of second -level indicators and the number of first -level indicators, and the final evaluation results are obtained based on the number of two people.

3. Experimental Analysis

This experiment targeted 200 middle-level employees from a large corporation, using the system described in this paper to collect psychological data of 200 employees and conduct evaluations of their mental health status. The system operates in a Windows 10 environment, with a 3.00GHz processor and 8.00GB of RAM.

3.1 Virtual Reality Simulation Effect Test

The simulation of a virtual reality environment is fundamental to conducting mental health status evaluations. The indices for measuring the virtual reality simulation's effectiveness include the spatial presence, engagement, ecological validity, and negative impact perceived by the 200 evaluators. The test results for the virtual reality simulation capability of the system are shown in Figure 5. According to the analysis Figure 5, it can be seen that the percentage of the sense of space presence, participation and ecological validity of the evaluation staff of this article exceeded 95%, of which the ecological effect is close to 100%, and the user's sense of space presence and participation are also high. The three are complementary to each other, and the negative impact percentage is always below 5%, and the negative impact is minimal. From this, it can be seen that the reviewers have a strong sense of immersion and presence when using this system. The virtual reality simulation effect of the system of this article is better.

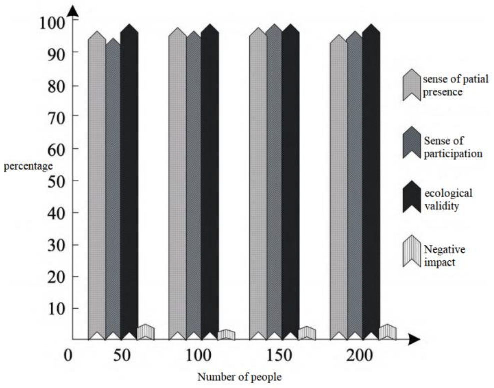

Figure 5. Virtual Reality Simulation Ability Test Results

3.2 Interactive Ability Test

The superior interaction performance enables the system to collect more of the mental health data of the evaluation personnel. To this end, the system delay is used as an index to measure the system interaction capability, and the interactive ability of the system is tested in this article. The results are shown in Figure 6.

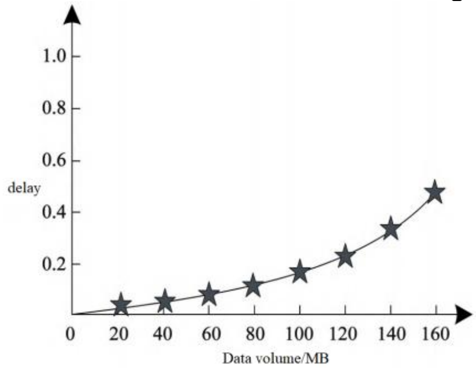

Figure 6. System Delay Test Results

Analysis of Figure 6 shows that as the amount of data increases, the system latency also increases. In the range of 0 to 100MB of data, the system latency shows a slow increasing trend. When the data volume exceeds 100MB, the increase in system latency is slightly more pronounced, but the maximum system latency is only 0.58s. This indicates that the system has low latency and good interactive capabilities.

3.3 Stability Test

Using the number of running threads of the system as an index to measure system stability, the system's stability was tested. The results are shown in Figure 7.

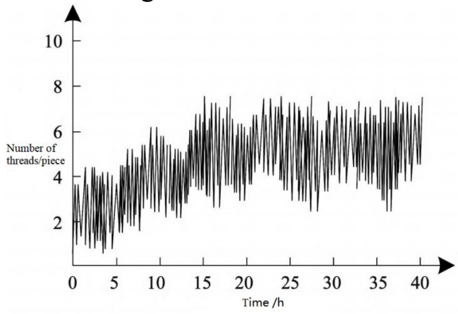

Figure 7. System Stability Test Results

Analysis of Figure 7 shows that as the system's runtime increases, the number of system threads first rises and then remains stable. In the first 15 hours of system operation, the number of system threads shows a slow upward trend, but the increase is not significant. After the system has been running for more than 15 hours, the number of running threads consistently remains within the range of [2,8]. This indicates that the number of threads during system operation is relatively stable, and the system's operational status remains stable throughout.

3.4 Mental Health Evaluation Capability Test

Taking the second-level indicators of mental health status as factors affecting the mental health of employees in that corporation, 200 employees were divided into five groups of 40 people each. The test aimed to assess the proportion of factors contributing to their mental health status for each group. The results are shown in Figure 8.

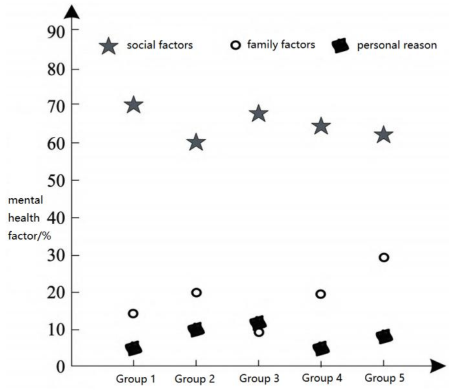

Figure 8. Mental Health Evaluation Results

Analysis of Figure 8 reveals that among the five groups of employees tested for mental health status, the primary factor affecting their mental health is social factors, followed by family and personal factors. Notably, the family factors for the third group of evaluators were lower than personal factors, which is attributed to differences in the test subjects. Across the five groups of evaluations, the highest proportion of social factors reached 70%, while the highest proportion of family factors was about 32%. This demonstrates that the broader social environment and the smaller family environment are the main factors affecting people's mental health conditions. Compared to social and family factors, personal factors have a smaller proportion. In summary, the system described in this paper can clearly and accurately evaluate employees' mental health conditions and analyze the factors affecting their mental health, indicating the strong evaluation capability of the system.

4. Conclusion

This study successfully evaluated the mental health status of 200 middle-level employees from a large corporation by developing a comprehensive assessment system. The system hardware includes a helmet display and data gloves, utilizing ARM processing submodules and FPGA programmable logic submodules to provide a highly interactive and immersive virtual reality experience. The software design employed the Analytic Hierarchy Process (AHP) and a fuzzy integration evaluation model to establish a mental health status indicator system, effectively assessing employees' mental health status. Experimental analysis demonstrated that the system has excellent interactive capabilities and stability, capable of accurately analyzing various factors affecting employee mental health.

The experimental results indicated that social factors are the primary factors affecting employee mental health, followed by family and personal factors. This finding underscores the importance of social and family environments in maintaining mental health. The system's high safety level and stable number of operating threads also prove its reliability in long-term operation.

Future research can be expanded and deepened in the following areas:

Technology Optimization and Innovation: With technological advancements, the design of the helmet display and data gloves can be further optimized to enhance system interactivity and immersion. Introducing more advanced data processing and analysis technologies, such as deep learning algorithms, could improve the accuracy and efficiency of mental health status assessments.

Multidimensional Data Analysis: Incorporating more types of data, such as physiological and behavioral data, into the mental health status assessment system to achieve a more comprehensive and multidimensional evaluation.

Personalized Assessment and Intervention: Developing personalized assessment and intervention plans based on the specific circumstances of different employees to more effectively promote employee mental health.

Broad Application and Popularization: Extending the application of the system to different sizes and types of enterprises, and even considering its application in other fields such as education and healthcare, to popularize the assessment and improvement of mental health.

Long-term Tracking and Evaluation: Implementing long-term tracking and evaluation of mental health status to monitor the effects of mental health intervention measures and adjust them as needed.

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