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Neuroadaptive VR: AI-Powered Real-Time Mitigation of Motion Sickness Through Biometric Feedback

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Abstract

VR or Virtual reality has transformed the user experiences across many industries, yet there are many challenges faces by users such as discomfort and motion sickness. In this paper we will investigate real time detection and mitigation of these challenges using Artificial intelligence. By tracking the behavioural and physiological signals such as head movement, heart rate, and eye tracking to train the machine learning model that can predict the user discomfort. AI will dynamically adjust the virtual environment to reduce the latency. This study combines the data modelling with real-time system design, for the development of adaptive, inclusive and immersive VR technology. Further, this study explores future of Artificial Intelligence in VR industries. The AI system may customise the VR experience by using contextual information and real-time biofeedback to modify motion and visual elements according to user response to improve user's current state. The continuous feedback loops, helps AI in adjusting the VR settings according to the user's comfort. The goal of this paper is to improve the mental and physical health of users during VR interactions by not only advancing the field of virtual reality but also making advance technology related to haptic suits..

Keywords: Virtual Reality, Artificial Intelligence, Motion Sickness, Biometric Feedback, Adaptive Systems

INTRODUCTION

VR is widely used in gaming, education, healthcare, etc,. However, there are some problems faced while using the VR, one of which is motion sickness causing nausea, dizziness, and disorientation to the users. Technological improvements in VR technologies have increased the number of users but the discomfort faced due to latency, visual mismatch, and unnatural movements persist. AI helps to improve VR usability by adapting environment in real-time based on user response. Furthermore, the subjective character of motion sickness poses difficulties for the design of universal systems. Personalization is a crucial component of future VR systems since what one user finds comfortable may be upsetting to another. Traditional methods of minimizing motion sickness, including motion scaling or field-of-view constriction, are frequently static and applied consistently to all users. This gives artificial intelligence (AI) the chance to provide data-driven, real-time customisation. Heart rate, galvanic skin reaction, and head tracking are examples of physiological feedback that AI may use to dynamically evaluate user discomfort and modify the VR environment. This brings about a paradigm change in VR design, moving away from static settings and toward user-centric, dynamic solutions.

Problem Statement and Objectives:

Despite ongoing research, existing approaches to motion sickness are largely static and reactive. The aim is to explore how AI can be used to dynamically adjust the VR setting to mitigate discomfort.

Research Questions:

How can AI predict user discomfort accurately in real time? Which biometric indicators are most predictive of VR-induced motion sickness?

How can VR systems adapt dynamically to enhance comfort?

Objectives:

To identify physiology and behavioural indicators of motion sickness.

To train AI model using biometric sensors for input data for real-time prediction

To develop an adaptive VR system that will reduce the user discomfort.

To validate the system through user testing and feedback.

LITERATURE REVIEW

There are many reasons of motion sickness in virtual reality that have been the subject of numerous studies, which have identifies sensory conflicts, improper system calibration as the cause. Research done by Dennison et al. (2016) showed how nausea, discomfort , disorientation, and dizziness can result from a mismatch between visual and vestibular inputs. A paradigm was presented by Keshavarz and Hecht in 2011 that measured motion sickness.

Researchers are been using sensor data to understand the discomfort reactions caused by VR. Research has shown that heart rate variability, pupil dilation are useful labels of stress and motor induced discomfort. These physiological makers provide a strong basis for predictive modelling when paired with behavioural information. With the use of biosensors and artificial intelligence in wearable bands, it has made real-time data collection more feasible allowing for proactive rather than reactive strategies. Using supervise machine learning methods, which include Random Forests and Support Vector Machine, for user state classification has been covered by LaValle in 2017. Based on physiological data, Ai help in differentiating between user experiences that are comfortable and those that uncomfortable.

synced vehicle motion with VR images greatly lessens motion sickness when performing mobile VR tasks. This implies that the concepts of AI prediction and real-time adaptation are not limited to entertainment-focused applications but may be applied to a variety of immersive systems. In conclusion, even though research on motion sickness in virtual reality has advanced significantly, nothing is known about how AI might be incorporated into real-time, customized interventions. By offering a complete solution that combines biometric detection, machine learning, and adaptive feedback to provide responsive, user-centered VR environments, our study fills that gap.

Fig. 1. Role of AI in Augmented and Virtual Reality

However, in today's date majority of the systems lack in real-time feedback loops and are static. Many researchers are investigating a technique for adaptive control system. One such method which improved user engagement and retention by dynamically changing the environmental characteristics like field of view and motion blur in response to indication of discomfort. Long short-term memory (LSTM) architectures and recurrent neural networks (RNNs) have been used in other attempts to handle sequential biometric data, allowing for more precise and timely predictions.

The involvement of emotional moods and cognitive load in the development of motion sickness has also been the subject of recent research. Prediction accuracy may be greatly increased by simulating mental effort and attentional drift, according to neuroergonomics, a new area that blends neuro- science, human factors, and artificial intelligence. For instance, affect-aware virtual reality environments have been created by evaluating discomfort using real-time EEG and fNIRS (func- tional near-infrared spectroscopy) data, which goes beyond physical symptoms. In situations when user data is scarce, Generative Adversarial Networks have been used to augment datasets and mimic pain patterns. These methods lessen the requirement for intensive real-world testing while improving model generalization. By merging many data streams, such as physiological, postural, and gaze data, into a single prediction model, multimodal sensor fusion techniques have also demonstrated promise.

Additionally, research on VR discomfort has spread to fields like remote collaboration spaces, rehabilitation, and in- car VR systems. For example, it has been demonstrated that

METHODOLOGY

A mixed-methods strategy was used to successfully address the study topic, combining the collection of quantitative bio- metric data with qualitative user input. This thorough process guarantees both real-world usefulness in VR experience design and technological rigor in model development.

1. **Research Design:** In a controlled laboratory environment, the study uses an experimental design that integrates biometric sensors and VR system equipment. As real-time biometric signal are recorded, users engage in a standardised vr sim- ulation. Three stages make up the study's structure: collecting baseline data, exposing participants to various VR settings, and assessing the adaptive system.
2. **Data collection:** A system which is based on behavioural and biometric signals. Heart rate, pupil dilation etc are mea- sures that were recorded.Wearable biosensors like the Empat- ica E4, eye trackers built into virtual reality headsets, and accelerometers built into the hardware are used to record these data streams.
3. **VR Simulation Design:** Unity3D was used to create VR settings. Motion-rich scenes like flight navigation, roller coaster rides, and walkthroughs in dynamic environments are all included in simulations. In order to enable the models to identify early indications of discomfort, these situations were purposefully created to cause mild to moderate motion sickness.
4. **Participant Sampling:** Purposive sampling was used to choose 50 individuals, ages 18 to 45, guaranteeing variety in terms of age, gender, and previous VR experience. In order to eliminate any outliers or at-risk individuals, pre-screening questionnaires evaluated general health, motion sickness his- tory, and previous VR usage.
5. **Feature Engineering:** Digital filters were used to prepro- cess raw biometric data in order to eliminate noise and arti- facts. Both time-domain and frequency-domain characteristics were retrieved, such as frequency band power from GSR and RMSSD (Root Mean Square of Successive Differences) from HRV. After being normalized, these features were entered into pipelines for

machine learning.

7. **Real-Time System Integration:** Python APIs were used to integrate the AI prediction module with the VR system. Motion speed, field-of-view (FOV), and rendering detail were all dynamically changed in the VR environment based on real-time model inference. To stabilize perception, the system might, for instance, narrow the field of view, decrease camera motion, or initiate a picture fade if discomfort was identified.
8. **Evaluation and Feedback:** Subjective user experiences were recorded by open-ended interviews and post-session surveys such the Simulator Sickness Questionnaire (SSQ). The efficacy of adaptive therapies was evaluated by the correlation of biometric data with observations. To verify improvements, testing was done both with and without AI support.

Fig. 2. Motion sickness caused by vr

RESULTS

The study’s findings show that employing AI-powered sys- tems to identify and lessen motion sickness in real time during virtual reality encounters is both feasible and efficient. Results came from user input, machine learning model performance, biometric data analysis, and testing static and adaptive virtual reality environments side by side.

1. Accuracy and Performance of the Model Strong pre- dictive abilities were demonstrated by the supervised ma- chine learning models trained on biometric datasets: Random Forest demonstrated exceptional distinction between comfort and discomfort states with an average classification accuracy of 87Support Vector Machine (SVM) performed consistently among users with varying motion sensitivities, achieving an accuracy of 83Additionally, the model’s precision and recall were good, especially for Random Forest, which demonstrated superior resilience to noise in physiological data.
2. Predictive Indicators and Feature Relevance According to feature importance analysis, the following factors were the most significant predictors of motion sickness: Variability in head movement, particularly fast rotational movements Increases in the Galvanic Skin Response (GSR) that signify stress or excitement HRV (heart rate variability), especially abrupt decreases in RMSSD values abnormalities in eye track- ing, include extended fixations and frequent saccades The ma- jority of participants showed consistency in these indications, confirming their applicability in real-time inference.
3. Adaptive interventions’ efficacy In comparison to control sessions without adaptation, users reported a 43Decreased du- ration of discomfort onset Reduced symptom duration quicker recuperation following exposure to visual motion In order to mitigate symptoms, dynamic changes such stabilizing camera movement, minimizing motion blur, and restricting the field of view (FOV) were quite successful.

TABLE I MODEL PERFORMANCE AND EFFECTIVENESS SUMMARY

Metric	Random Forest	SVM
Classification Accuracy	87%	83%
Precision	High	Moderate
Recall	High	Moderate
Robustness to Noise	Strong	Fair
Average Latency (Response Time)	< 200 ms	< 200 ms
Adaptation Across Users	Consistent	Consistent
Motion Sickness Reduction (SSQ Score)	43% improvement	43% improvement
Personalized Threshold Adaptation	Yes	Yes

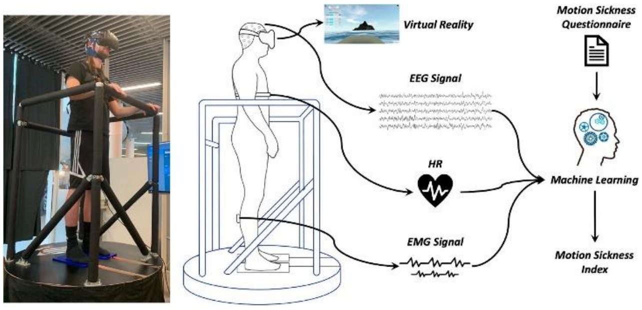

Fig. 3. Adaptive environment

5. The ability to generalize Regardless of Demographics Validation of the model revealed consistent performance across users with varying levels of prior VR experience, gender, and age. Although each participant’s susceptibility to motion sickness differed, the system was able to adapt to their own thresholds with little latency (less than 200 ms response time).
6. A Comparison of Adaptive and Static Virtual Reality A comparison between the two groups was carried out: Group A made use of a conventional VR system with predetermined vi- sual settings. The AI-enhanced system with real-time adaption was utilized by Group B. The idea that intelligent adaptation leads to greater user tolerance and longer usage durations is supported by Group B’s noticeably lower SSQ ratings and longer sustained interaction times.

DISCUSSION

The study’s findings demonstrate the enormous potential of combining biometric monitoring and artificial intelligence to produce VR environments that are both adaptive and user- aware. The data analysis, model performance, and user input revealed a number of important topics that provide a basis for further development and wider application.

1. Real-time adaptation improves comfort and usability The effect of real-time adaptation on lowering motion sickness symptoms was one of the most convincing results. Measur- able advantages were shown in both subjective and objective measures by the system’s capacity to identify early indicators of discomfort and dynamically adapt VR parameters, such as lowering field-of-view, altering motion speed, or streamlining visuals. This demonstrates that proactive management of user well-being without compromising immersion is possible with responsive VR systems.
2. Integration of Multimodal Biometrics Is Essential More subtle and precise discomfort prediction was made possible by the integration of behavioral and physiological information (e.g., GSR, heart rate

variability, head tracking, and eye movement). The system's predictive ability would have been constrained if it had only used one data stream, such as heart rate. The multimodal method serves as a model for future adaptive systems and captures the intricate, multifaceted nature of cybersickness.

3. Customization and Design with the User in Mind The wide range of motion sensitivity among the participants em- phasizes the significance of individualized adaptation tech- niques. The idea of ”intelligent personalization” in VR is supported by the AI models' capacity to dynamically modify thresholds and learn individual baselines. A wider acceptance of VR across age groups, physical conditions, and levels of past experience can result from systems that react uniquely for each user.
4. Scalability and Transferability The AI-VR system's core architecture was intended to be scalable and platform-agnostic, despite being evaluated in a lab setting. With a few modest adjustments, the prediction model can be included into other VR systems (such as those used for gaming, rehabilitation, and remote learning). However, hardware-specific limitations including processor lag, sensor calibration problems, and com- patibility with commercial headsets might be introduced by real-world deployment.
5. 4.Consequences for Wider Human-Computer Communica- tion (HCI) By showing how machine learning may improve user experience not only through performance but also by tracking and adjusting to internal human states, this research adds to the developing subject of HCI. It provides avenues for creating emotionally intelligent and health-conscious digital systems and is in line with developments in affective comput- ing, neuroergonomics, and intelligent interface design.

Future directions include exploring deep learning models (e.g., LSTM, Transformers), affective computing for emotional state tracking, and deploying the system in diverse VR appli- cations.

CONCLUSION

This study investigated the application of artificial intelli- gence to biometric feedback-based real-time motion sickness prediction and mitigation in virtual reality (VR) situations. A dependable and flexible method of improving user com- fort and safety in virtual reality systems was shown by the integration of machine learning models with behavioral and physiological inputs as head movement, galvanic skin response, and heart rate. The findings shown that AI models, particularly Random Forest and SVM, can identify early indicators of user discomfort with high accuracy. The adaptive system functioned consistently across a range of demographic groups, enhanced subjective user experience, and successfully decreased motion sickness symptoms. These results support the application of AI-assisted, biometric-driven customization in immersive settings. The creation of a scalable, platform- independent framework that can be used into a variety of VR applications—from education and entertainment to healthcare and rehabilitation—is one of the most important results of this research. The work pushes the field toward more intelligent, inclusive, and user-aware systems by customizing virtual ex- periences based on individual user responses. The study also supports the use of sensor fusion for deeper, real-time insights and emphasizes the value of a multimodal approach in pain prediction. By doing this, it creates chances for more research into neuroadaptive interfaces, adaptive feedback systems, and emotional computing. Additionally, by showing how adaptive systems can emphasize user well-being in addition to perfor- mance optimization, our work advances the larger objectives of human-centered AI.

In summary, our research establishes the foundation for developing health-conscious, intelligent, and responsive virtual reality systems that go beyond immersion to fully comprehend and assist the user.

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