



College of Engineering

CS 25-315

Emotion Recognition in VR Using
Advanced AI

Preliminary Design Report

Prepared for
Kostadin Damevski
VCU College of Engineering

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Executive Summary

The rapid advancement of virtual reality (VR) technology presents new opportunities and challenges for various industries, including entertainment, education, healthcare, and beyond. As VR continues to evolve, understanding and measuring emotional states within these environments has become crucial for improving user experiences and optimizing performance. This project, sponsored by Kostadin Damevski of the VCU College of Engineering, aims to develop an AI-driven emotion recognition system in virtual reality environments, focusing on accurate real-time detection of emotional states.

The shift to immersive virtual experiences introduces complexities in interpreting emotional cues. Unlike traditional face-to-face interactions, VR interactions lack the natural flow of non-verbal communication, such as body language and facial expressions. This project seeks to address this gap by integrating advanced emotion recognition technology into VR, offering a more nuanced understanding of user emotions during their interaction within these environments.

The primary stakeholders in this project include VR developers, organizations adopting VR technology, and researchers focusing on human-computer interaction (HCI). By leveraging AI, the project will enhance the ability to gauge emotional states through facial expressions. The goal is to create an advanced system capable of real-time emotion recognition, offering actionable insights for a wide range of VR applications.

Conducted at the Software Improvement (SWIM) Lab at VCU, this project builds on existing research in emotion recognition and extends it to dynamic VR environments. Our approach will explore how emotion recognition can be adapted to VR settings, making use of AI to provide an in-depth understanding of emotional responses, thus enhancing the overall user experience.

Key objectives of the project include:

1. Developing an advanced AI system for accurate emotion measurement in VR.
2. Developing an emotion gathering tool in VR.
3. Conduct a study to elicit emotional reactions from participants and to draw distinctions between 'real' and 'fake' emotional responses.
4. To assemble a dataset composed of avatar images and landmark data from the emotional reactions of study participants.

The design of the system will prioritize real-time processing capabilities, ensuring seamless integration with existing VR platforms. The tool will also feature non-intrusive

feedback mechanisms that are both user-friendly and respectful of privacy. By focusing on reducing cognitive load and providing real-time emotional insights, the system will optimize VR experiences while adhering to industry standards and user data privacy regulations, including GDPR and HIPAA compliance.

The success of this project will not only advance the field of emotion recognition within VR but also have broad implications for improving user experiences across a range of VR applications. By making VR environments more emotionally aware, this project will contribute to more immersive, effective, and human-centered virtual experiences in a variety of fields.

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Section A. Problem Statement

The rapid advancement of virtual reality (VR) technology has opened new avenues for immersive experiences in a variety of sectors, including gaming, training simulations, education, and mental health treatment. However, a significant gap exists in these applications: the ability to understand and interpret users' emotions in real-time. The challenge lies in creating systems capable of accurately detecting and responding to users' emotional states within VR environments. This inability to assess emotional responses limits the effectiveness of VR in applications where emotional engagement is crucial, such as in therapeutic VR, interactive gaming, or VR-based training simulations.

Emotion recognition is a fundamental aspect of human interaction, helping individuals gauge reactions, make decisions, and maintain social cohesion. In VR environments, understanding emotional responses could significantly enhance the user experience by making it more personalized and adaptive. Current methods of emotion recognition, however, are limited by the lack of non-intrusive, real-time solutions. Conventional emotion recognition tools, such as those relying on physiological sensors or facial expression tracking using external cameras, are either cumbersome, intrusive, or not scalable across various VR platforms.

This project aims to address the gap in VR by developing an emotion recognition system that uses avatars and facial landmarks within a VR environment, processed by artificial intelligence (AI) in real-time. By creating a system that can interpret emotions based on users' interactions with virtual environments, avatars, and stimuli, the design seeks to improve the interactivity and effectiveness of VR applications.

The stakeholders in this project include VR users (particularly in fields like mental health therapy, education, and gaming), VR developers, and researchers. Specific groups that will benefit from this emotion recognition system include:

1. **Therapists and Psychologists:** VR has already been used in mental health therapy (e.g., exposure therapy for PTSD). Emotion recognition will further personalize these sessions and make the experience more effective by allowing real-time adaptation based on the user's emotional responses.
2. **Educators:** Immersive VR training environments could be significantly enhanced by detecting and responding to students' emotional states. For instance, if a student shows frustration, the VR system could adjust the difficulty level or offer help.
3. **Game Developers:** VR games can be made more interactive and immersive by recognizing emotional cues, leading to more engaging gameplay that responds dynamically to players' emotional states.
4. **Researchers and Developers in AI and VR:** This technology advances the development of emotion recognition systems within VR and AI, providing valuable insights and tools that can be applied to various industries.

The need for emotion recognition in VR is widespread and growing, particularly as VR becomes more integrated into industries like healthcare, education, and entertainment. Technology is particularly important in fields like telemedicine, where clinicians are increasingly conducting consultations through VR, and in education, where VR is used for simulations and immersive learning experiences. However, these fields currently lack the capability to gauge emotional responses effectively, which limits the ability to tailor experiences to individuals in real time.

The potential costs of not addressing this problem are multifaceted. Economically, industries such as healthcare and gaming are missing opportunities for enhanced, user-responsive experiences that could improve outcomes and engagement. In healthcare, for instance, without emotion recognition, therapy might be less effective, delaying patient recovery and potentially increasing healthcare costs. In the gaming industry, failing to incorporate emotional feedback could result in less engaging experiences, ultimately leading to lower user retention rates.

This project is developed under the guidance of Kostadin Damevski and the SWIM (Software, Interaction, and Media) Lab. The SWIM Lab specializes in the development of innovative software solutions and immersive technologies that enhance user experience.

Section B. Engineering Design Requirements

B.1 Project Goals (i.e. Client Needs)

The overarching goals of this project, as specified by the client and stakeholders, focus on improving VR interactivity by integrating emotion recognition. These goals are derived from the unmet need to create adaptive VR experiences that respond to users' emotional states in real-time, enhancing user engagement and improving outcomes in applications like therapy, education, and entertainment. The primary goals are as follows:

- To develop a VR-based emotion recognition system that accurately detects emotional states of users.
- To improve user engagement and immersion in VR environments through real-time emotional feedback.
- To integrate AI with VR technology in a way that minimizes user intrusion and maximizes immersion.
- To ensure the solution is scalable across different VR platforms and adaptable to various use cases.

These goals will serve as the foundation for the design process, ensuring the final solution meets client and user needs in a practical and efficient manner.

B.2 Design Objectives

The design objectives are specific tasks that the system must achieve to meet the project goals. These objectives will guide the development of the emotion recognition system and ensure it aligns with the stakeholders' needs. Each objective is SMART: Specific, Measurable, Achievable, Realistic, and Time-bound.

- The design will accurately detect users' emotional states based on their facial expressions and interactions within a VR environment.
- The design will process emotional data in real-time with a response time of less than 100 milliseconds.
- The design will ensure the system is scalable, able to function across multiple VR platforms (e.g., Meta Quest, Oculus Rift).
- The design will use AI algorithms that are capable of analyzing facial landmarks and avatars to determine emotional states with at least 85% accuracy.
- The design will integrate seamlessly into existing VR systems with minimal disruption to the user experience.
- The design will minimize latency and maintain a frame rate of 60 frames per second (FPS) to ensure smooth interaction and immersion.

These objectives will drive the design process and be linked to corresponding design specifications and constraints to ensure that the final product meets expectations.

B.3 Design Specifications and Constraints

Functional Constraints:

- The emotion recognition system must detect emotional states with at least 85% accuracy based on facial landmarks within the VR environment.
- The system must be compatible with major VR platforms, including Meta Quest and Oculus Rift, ensuring wide usability.

Performance Constraints:

- The system must maintain a frame rate of 60 FPS for smooth and immersive user interaction.
- The system must operate within a response time of 100 milliseconds to ensure real-time emotion recognition without disrupting the VR experience.
- The system must be capable of processing emotional data in real-time, without noticeable lag or delays.

Usability Constraints:

- The design must be user-friendly and require minimal setup for end-users, ensuring ease of integration into existing VR platforms without requiring external devices beyond the VR headset.

Regulatory Constraints:

- The system must comply with general data privacy and security standards, ensuring that all emotional data is handled securely and in accordance with relevant regulations (e.g., GDPR for European users).

B.4 Codes and Standards

Codes relevant to our design:

1. General Data Protection Regulation (GDPR) – EU Regulation 2016/679

- Relevance: This code governs data privacy and security for any systems processing the personal data of EU citizens. Since the tool will collect and process sensitive user data (emotions, facial expressions, speech), compliance with GDPR is essential.

- Key Constraints: Data processing must be transparent, secure, and with the user's consent. Data should be anonymized or encrypted, and users must have the right to access, rectify, or delete their data.

2. Health Insurance Portability and Accountability Act (HIPAA) – U.S. Public Law 104-191

- Relevance: If the tool is used by health-related entities or individuals, HIPAA may apply, especially if it collects any data related to health metrics or well-being.

- Key Constraints: The design must ensure the confidentiality and integrity of health-related information, and encryption must be used when transmitting sensitive data over networks.

3. Occupational Safety and Health Administration (OSHA) Standard 29 CFR 1910

- Relevance: This code relates to workplace safety, which could be relevant if the emotion recognition tool is used in workplace settings to assess worker well-being and stress.

- Key Constraints: The design must not contribute to excessive screen time or cognitive overload, which could negatively impact the user's health and safety.

Standards relevant to our design:

1. IEEE Standard 802.11 – Wireless LAN Standards

- Relevance: This standard governs wireless communications, ensuring the tool can efficiently transmit data over wireless networks (Wi-Fi) used in remote work setups.

- Key Constraints: The tool must be able to operate over standard Wi-Fi networks with minimal latency to ensure real-time processing. Communication protocols must ensure reliable and secure data transmission.

2. ISO/IEC 27001 – Information Security Management

- Relevance: This standard provides requirements for managing sensitive information securely, making it crucial for the tool's data handling procedures.

- Key Constraints: The tool must have controls in place for confidentiality, integrity, and availability of data. This includes encryption, access control, and regular security audits to ensure compliance with this standard.

3. IEEE Standard 1789-2015 – Recommended Practices for Modulating Current in High-Brightness LEDs

- Relevance: If the design involves a user interface with LED-based notifications or feedback, this standard addresses health concerns related to the flicker of LED lighting.

- Key Constraints: Ensure any visual feedback from the tool's user interface avoids flicker frequencies that could lead to discomfort, fatigue, or cognitive strain for users.

4. ISO 9241-210:2019 – Ergonomics of Human-System Interaction

- Relevance: This standard applies to the user interface and user experience design, ensuring that the tool's interaction with users is ergonomic and minimizes cognitive load.

- Key Constraints: The interface must be intuitive and not detract from the main tasks in remote work meetings. Visual feedback should be designed to be clear and non-intrusive.

Section C. Scope of Work

C.1 Deliverables

Academic Deliverables

- Team contract
- Project proposal
- Preliminary design report
- Fall poster
- Final design report
- Capstone EXPO poster

Project Deliverables

- Experiment results comparing the accuracy and performance of AI models trained with human faces, avatars, or landmarks
- Spreadsheet containing emotion recognition datasets
- Final iteration of the emotion recognition AI tool
- Emotion gathering tool to be used in an emotion dataset construction experiment
- Final emotion dataset assembled from experiment

Deliverables Requiring Access to Campus

- Design Poster and Capstone EXPO poster: These will require campus access for printing. All team members regularly access campus and are physically able to print.

Remote Work Capabilities

- All coding, AI training, and other non-printing tasks can be performed remotely.

Resources Needed for Effective Remote Work:

- Access to the High-Performance Research Computing clusters at VCU
- GitHub repository for sharing code and other collaborative work

C.2 Milestones

Milestone	Description	Estimated Duration	Completion Date
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1. Research Benchmarks and Existing Approaches	Conduct research on benchmarks and existing emotion recognition-based machine learning approaches.	10 days	Sept. 20
2. Choice of Architecture	Select the architecture to base the project on.	10 days	Sept. 30
3. Training of Models	Train models based on the chosen architecture.	4 weeks	Oct. 16
4. Report on Benchmark Tool Performance	Document the use of benchmark tools to test the performance of the model.	3 weeks	Nov. 7
5. First Framework of Emotion Recognition Tool	Develop the initial framework for the emotion recognition tool.	6 weeks	Nov. 25
6. Feedback Implementation for Second Draft	Implement feedback into the second draft of the emotion recognition tool framework.	3 weeks	Dec. 12
7. Development of Backend	Develop the backend for the emotion recognition AI tool prototype.	6 weeks	Jan. 30
8. Model Implementation into Prototype Software	Integrate the trained model into the prototype software.	4 weeks	Feb. 20
9. Development of Frontend	Create the frontend for the emotion recognition AI tool prototype.	3 weeks	March 12
10. Changes Based on Sponsor Feedback	Implement changes to the emotion recognition AI tool based on feedback from the sponsor.	3 weeks	April 1
11. Preparation for Expo Presentation	Prepare for the presentation of the emotion recognition AI tool at the expo.	3 weeks	April 22

C.3 Resources

Hardware

- The VCU High Performance Research Computing Core: For the training of the models used for emotion recognition. Access to already given by faculty sponsor.

- Meta Quest Pro headset: For assessing potential of VR and avatar in creating an emotion recognition tool.

Databases

- 17 datasets outlined in Osman (2024): In use to train the model for increased out-of-domain robustness. Access given by faculty sponsor

Libraries

- The Pytorch Library: Library needed for deep learning capabilities. Publicly available

Section D. Concept Generation

Sub-section 1: Emotion Recognition Tool

Option 1: Emotion Recognition via Avatar and Landmarks with VR and AI

This option involves using emotion recognition models trained with avatar facial expressions and landmarks within a VR environment. The system will leverage AI algorithms to analyze the facial landmarks (points on the face) and avatars to detect emotions in real-time. This approach avoids the need for physical wearable devices and uses data from virtual characters (avatars) and facial landmarks within VR interactions.

- How This Addresses the Problem:
 - Offers a non-intrusive emotion recognition solution for VR environments, particularly in virtual meetings, training, or gaming.
 - Utilizes advanced AI and machine learning models to provide real-time emotion feedback based on avatars' visual and emotional reactions.
- Pros:
 - No need for additional hardware beyond the VR headset, making it more user-friendly and affordable.
 - Scalable across various VR platforms without requiring additional sensors.
- Cons:
 - Accuracy may depend on the quality of the avatars and the level of interaction in the VR environment.
 - Could face limitations in detecting emotions that are not well-expressed by avatars or facial landmarks.

Option 2: Emotion Recognition with Wearables

In this option, the emotion recognition tool uses wearable devices (e.g., heart rate monitors, skin conductance sensors, etc.) alongside the VR environment to detect emotions. The wearables would provide physiological data that, when integrated with the AI, would enhance emotion recognition accuracy.

- How This Addresses the Problem:
 - Combines physiological data with visual data to increase the accuracy of emotion recognition in VR.
 - This system would be ideal for use cases where emotional states are critical, such as therapeutic VR applications or mental health monitoring.
- Pros:

- o More accurate emotion detection as it incorporates physiological responses that may not be captured through visual data alone.
 - o Provides a more holistic understanding of the user's emotional state.
- Cons:
 - o Increased cost and complexity due to the need for wearables.
 - o Wearables could disrupt the user experience, especially in immersive VR environments.

Section 2: Experiment Design

Option 1: Video-based Experiment

In this option, participants will wear the VR headset and watch emotionally engaging videos (e.g., dramatic scenes, emotional narratives, etc.). Their avatars will react to these videos, and their facial expressions/landmarks will be recorded as emotion data.

- How This Addresses the Problem:
 - o Allows controlled emotional responses to pre-determined video stimuli.
 - o Provides clear emotional cues to analyze, as participants' facial expressions are guided by the video content.
- Pros:
 - o Controlled environment with known stimuli, making it easier to elicit specific emotional reactions.
 - o Simpler to implement and manage for the study as it doesn't require complex interactivity.
- Cons:
 - o Limited to the emotional responses that the video can evoke.
 - o Less natural than games, as real-time interaction with the environment is missing.

Option 2: Game-based Experiment

In this alternative, participants engage in a VR-based game where they navigate emotionally challenging scenarios, and their avatars react accordingly. The emotional responses during gameplay will be recorded and analyzed for emotion recognition.

- How This Addresses the Problem:
 - o Provides a more dynamic and natural method for eliciting emotional reactions, as players respond to real-time challenges.
 - o The game offers a richer set of scenarios for testing emotional responses, including problem-solving, conflict resolution, and emotional stress.
- Pros:
 - o More interactive and engaging for participants, which can lead to more genuine emotional responses.

- o Allows for a broader range of emotional reactions based on gameplay dynamics.
- Cons:
 - o More complex to develop and manage due to the need for interactive, real-time scenarios.

Section E. Concept Evaluation and Selection

Decision Matrix 1: Emotion Recognition Tool

Now that we have two options for emotion recognition, we will evaluate them based on the following criteria: Performance (Accuracy), Cost, Reliability, Risk, Scalability, and Time to Implementation.

<i>Criteria</i>	Avatar & Landmarks with VR and AI	Wearables for Emotion Recognition
Performance (Accuracy)	3 (Good accuracy with visual data but limited by avatar design)	5 (Enhanced accuracy with physiological data integration)
Cost	4 (Low cost, only requires VR hardware)	2 (High cost due to additional wearables and sensors)
Reliability	4 (Reliable once implemented, but depends on avatar quality)	4 (Wearables are generally reliable but require calibration)
Risk	4 (Risk of inaccuracies based on avatar quality and interactions)	3 (Risk of discomfort or interference from wearables, as well as privacy concerns)
Scalability	5 (Easily scalable, no need for additional hardware)	3 (Less scalable due to reliance on wearable technology)
Time to Implementation	4 (Moderate development time for VR and AI integration)	3 (Longer due to integration of wearables and calibration)
Total Score	24	20

Discussion of Results

Avatar & Landmarks with VR and AI: This option has high scalability and relatively low cost but suffers from limitations in accuracy and potential reliance on avatar quality. It is a great choice if affordability and scalability are priorities.

Wearables for Emotion Recognition: This option is more accurate and reliable but incurs higher costs and complexity. It also faces potential issues with scalability due to the reliance on external hardware.

Decision Matrix 2: Experiment Design

For the experiment design section, we will evaluate the two options (Video-based vs. Game-based) using similar criteria: Performance (Data Quality), Reliability, Risk, Scalability, and Time to Implementation.

<i>Criteria</i>	Video-based Experiment	Game-based Experiment
Performance (Data Quality)	4 (High-quality data, controlled emotional stimuli)	5 (Rich emotional responses, dynamic and interactive)
Reliability	5 (Highly reliable, controlled environment)	3 (Less predictable, depends on player behavior)
Risk	3 (Risk of limited emotional responses from videos)	4 (Risk of varied responses due to gameplay unpredictability)
Scalability	4 (Easily scalable, minimal setup)	3 (Requires environment modification for each new game)
Time to Implementation	4 (Quick to implement with existing video content)	2 (Longer time required to develop or modify interactive games)

Total Score	20	17
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Discussion of Results

Video-based Experiment: This option is highly reliable and cost-effective, making it an ideal choice for a controlled study. It also scales easily and can be implemented quickly.

Game-based Experiment: This approach offers richer emotional data and is more engaging for participants but comes with higher costs, longer development times, and less reliability due to the unpredictability of player responses.

Section F. Design Methodology

In this project, the iterative engineering design process will be used to refine and optimize the design of the emotion recognition system using virtual reality (VR) and artificial intelligence (AI), as well as the associated experimental design. The final design must meet the previously established design objectives and specifications, which include functionality, performance, user experience, and cost-effectiveness. To ensure these requirements are met, we will use a combination of computational modeling, experimental testing, and validation procedures.

F.1 Evaluation of the Initial Design Concepts

The evaluation phase involves assessing the initial design concepts and iterating them based on feedback, performance metrics, and practical constraints. In this case, we are considering two primary components for evaluation:

1. The emotion recognition tool (which could involve VR and AI using avatars and landmarks).
2. The experimental design (video-based emotion elicitation).

During the early phases, simplified criteria such as performance (accuracy), reliability, scalability, and cost will be used. These criteria will be revisited and refined as more detailed specifications are developed.

F.2 Improvement through Iteration

Once the initial design concept is chosen, it will undergo iterative improvements using computational modeling and simulations. Specifically:

- **AI-based Emotion Recognition Model:** The emotion recognition system will use AI algorithms trained on datasets such as FER2013. The model will be iteratively improved using machine learning techniques (e.g., supervised learning) to achieve higher accuracy. The model will be tested and improved through validation against real data obtained during the experiment, adjusting parameters like learning rates, feature extraction techniques, and model architecture. This iterative training process will allow us to refine the model's ability to detect emotions based on facial expressions and landmarks in the VR setting.

F.3 Verification of Design Specifications

Accuracy of Emotion Recognition: During verification, the emotion recognition system will be tested using both real-time data and pre-recorded datasets (such as FER2013). We will measure the accuracy, precision, and recall of the system in detecting emotions (e.g., happiness, sadness, anger, etc.) from avatars and landmarks in VR scenarios. The model will undergo rigorous testing under different scenarios to ensure it meets the required detection accuracy.

F.4 Experimental Testing Methodology

The following testing methods will be employed to validate and improve the design:

- **Participant Testing:** For both the VR-based emotion recognition system and the experimental content, we will conduct controlled human-subject experiments in which participants are exposed to various stimuli (video or game content). In the case of the VR emotion recognition tool, participants will wear VR headsets while interacting with avatars
- **Testing Equipment:** For the VR emotion recognition tool, testing will require VR headsets, motion-tracking cameras, and possibly wearable sensors (e.g., heart rate monitors, EMG sensors, or EEG devices) to monitor physiological responses. In the case of video-based or game-based experiments, cameras will record facial expressions, and emotion tracking software will analyze these responses.
- **Data Acquisition and Instrumentation:** Data from the facial expressions, physiological sensors, and avatar interactions will be collected using motion-tracking systems integrated with Unity or another VR platform. Data will be processed in real-time to extract features (such as facial landmarks or physiological responses) that are indicative of emotional states.

F.5 Validation Procedure

Steps for Client Validation:

- **Prototype Demonstration:**
 - **Timing:** A formal demonstration of the final prototype will take place toward the end of the project, approximately in late March or early April. The prototype will include the emotion recognition tool integrated with VR and the emotion gathering tool.
 - **Procedure:** The design team will provide the client with a live demonstration of the emotion recognition system. This will include showing how the system identifies emotional states through avatars and landmarks in VR, and how the experiment (video-based or game-based) works in practice.
 - **Expected Outcome:** The client will observe the functionality of the system and verify that the tool works as intended, confirming its ability to detect and assess emotions accurately in real-time.
- **Review of Experimental Results:**

- o The design team will present the resulting dataset from the experiment. This will include data on how well the emotion recognition tool performs with real users.
- o The team will share simulation results, demonstrating the tool's ability to process emotions in real-time and handle various types of stimuli (videos vs. games).
- o Expected Outcome: The client will verify that the system performs as expected, with emotion recognition accuracy and other performance metrics meeting the required thresholds.

Section G. Results and Design Details

Emotion Recognition Tool (VR and AI Integration)

- **AI Emotion Recognition Model:** We utilized a FER2013 pre-trained model to recognize facial expressions in real-time through both VR avatars and landmarks. The prototype model demonstrated an accuracy rate of roughly 65% when tested with both real-time avatar faces and test images from the dataset. However, the accuracy is 99% when tested on the training images from the dataset, indicating that the model has suffered overfitting.

Performance Metrics:

- o **Accuracy:** 65% (on real-time and non-training images)
- o **Processing Time:** The emotion recognition process was completed in <1 second per frame, ensuring real-time performance.
- o **Emotion Categories:** Happy, Sad, Anger, Disgust, Fear, Surprise, Neutral

Key Computational Result: The AI-based emotion recognition tool can process facial expressions through avatars in VR, ensuring that emotions are detected in a timely manner. However, the model used within the tool must be adjusted to account for low accuracy.

Section H. Societal Impacts of Design

H.1 Public Health, Safety, and Welfare

The design of the emotion recognition system primarily impacts public health, safety, and welfare by ensuring that emotional data is used responsibly and accurately in critical environments, such as mental health interventions and therapeutic applications. The system's use in VR-based therapy, for example, could provide valuable emotional feedback to mental health professionals, improving patient care.

- **Safety Features:**
 - **Data Privacy:** As the system collects sensitive emotional data, ensuring robust data security protocols, including encryption and anonymization, is essential to safeguard users' privacy.
 - **Non-intrusive Nature:** The use of avatars and AI algorithms for emotion recognition eliminates the need for wearable sensors, reducing the physical burden on users and enhancing comfort during VR-based sessions.
- **Potential Effects:**
 - **Positive Impact:** The emotion recognition tool could help identify early signs of emotional distress or mental health issues, allowing for timely interventions in therapeutic settings.
 - **Negative Impact:** If improperly used or misinterpreted, emotion data could lead to inaccurate conclusions about a person's emotional state, potentially causing harm in clinical or professional settings.
- **Standards and References:** The design adheres to privacy and health data regulations, including HIPAA for healthcare applications and GDPR for data protection in the European Union.

H.2 Societal Impacts

The widespread use of emotion recognition systems integrated with VR and AI has significant potential to change how people interact with each other. In contexts such as virtual meetings, training, or gaming, this technology enables real-time emotional feedback, fostering more empathetic and responsive interactions between users.

- **Positive Impacts:**
 - **Enhanced Communication:** Emotion recognition can make virtual interactions more authentic by enabling participants to perceive and respond to emotional cues, improving communication and understanding, particularly in online meetings.

- o **Therapeutic Applications:** In mental health and wellness, the technology could help monitor emotional responses, enhancing therapeutic interventions and offering new tools for psychological care.
- **Negative Impacts:**
 - o **Social Isolation:** Excessive reliance on virtual interactions might discourage face-to-face communication, potentially leading to increased isolation.
 - o **Over-reliance on Technology:** There is a risk of people becoming too reliant on AI-driven systems to interpret emotional cues, potentially undermining the importance of human intuition and judgment.

H.3 Political/Regulatory Impacts

The integration of emotion recognition technology into VR and AI could have various political and regulatory implications. As emotional data is highly sensitive, there are potential legal concerns regarding how this data is collected, stored, and used.

- **Regulatory Concerns:**
 - o **Privacy Regulations:** Given that emotional data can reveal personal, psychological states, government regulations around data privacy will play a significant role. Ensuring that the system complies with existing regulations such as GDPR, CCPA, and other national data protection laws is critical.
 - o **Ethical Standards:** Lawmakers may enact new regulations specific to emotion recognition technologies, especially if these systems are used in critical sectors like healthcare, where emotional data could influence diagnoses or treatments.
- **Political Implications:**
 - o **Surveillance:** The technology might be viewed as an invasive tool, potentially raising concerns about government or corporate surveillance if the data is used without proper oversight.

H.4 Economic Impacts

Emotion recognition tools in VR and AI have the potential to disrupt several markets, especially in sectors such as virtual reality, mental health services, and workplace training.

- **Positive Economic Impact:**
 - o **Growth in VR and AI Markets:** The adoption of emotion recognition in VR platforms could stimulate growth in both the VR and AI industries, particularly in sectors like remote work, training, and healthcare.
 - o **Job Creation:** The implementation of AI-driven systems in various fields may lead to the creation of jobs, especially in areas related to AI development, data security, and healthcare.
- **Negative Economic Impact:**
 - o **Job Displacement:** As emotion recognition and AI technologies are incorporated into various sectors, there may be job displacement in areas where human

interpretation of emotions is traditionally employed (e.g., therapists, customer service agents).

- o Costs of Implementation: The high costs of developing and implementing such advanced AI and VR technologies could limit accessibility, especially for smaller companies or less developed regions.

H.5 Environmental Impacts

The environmental impacts of the emotion recognition system primarily stem from the use of VR hardware and AI systems, which require resources for manufacturing and energy for operation.

- Positive Environmental Impact:
 - o Reduction in Travel: VR technology, integrated with emotion recognition, could reduce the need for in-person meetings and travel, contributing to lower carbon emissions.
- Negative Environmental Impact:
 - o Energy Consumption: The computing power needed for AI and VR processing could lead to high energy consumption, especially in large-scale implementations.
 - o E-Waste: As with all electronic devices, the widespread use of VR headsets and other hardware could contribute to e-waste if not properly recycled.

H.6 Global Impacts

Emotion recognition technology has the potential to influence global markets, particularly in sectors such as healthcare, entertainment, and remote work.

- Positive Global Impact:
 - o Global Health Applications: Emotion recognition could enhance the ability to monitor and provide emotional support on a global scale, particularly in telemedicine and remote therapy services.
 - o Cross-Cultural Communication: The use of AI and VR in global settings may bridge cultural gaps by allowing real-time translation of emotional cues, promoting better understanding in international interactions.
- Negative Global Impact:
 - o Global Inequality: Technology could widen the gap between developed and developing nations if access to advanced AI and VR systems is limited in lower-income countries.
 - o Privacy Concerns: The potential for mass surveillance and data misuse could have global repercussions, particularly if personal emotional data is exploited without proper safeguards.

H.7. Ethical Considerations

The use of emotion recognition in VR and AI raises several ethical concerns, particularly regarding privacy, consent, and the potential misuse of emotional data.

- **Privacy and Consent:**
 - **Informed Consent:** It is essential that users fully understand how their emotional data will be used and are given the option to opt-out of data collection at any point.
 - **Data Misuse:** There is a risk that emotional data could be exploited by organizations, especially in marketing or surveillance without user consent.
- **Bias and Fairness:**
 - **Algorithmic Bias:** Emotion recognition systems could inadvertently exhibit bias, especially if they are trained on datasets that do not represent the full diversity of emotional expressions across different cultures, ages, and genders. Steps must be taken to ensure the system is fair and unbiased.
- **Moral Implications:**
 - **Manipulation:** There is the potential for the technology to be used manipulatively, such as exploiting emotional vulnerabilities in consumers or employees. This raises questions about the ethical responsibility of those deploying the system.

Section I. Cost Analysis

Bill of Materials:

<i>Item</i>	<i>Vendor</i>	<i>Unit Cost</i>	<i>Quantity</i>	<i>Total Cost</i>	<i>Delivery Time</i>	<i>Date Received</i>
Meta Quest Pro VR Headset	Meta (formerly Oculus)	\$1,000	2	\$2,000	N/A	N/A

Total Costs Incurred to Date

- VR Headsets: \$2,000 (2 Meta Quest Pro units)
- Total Cost to Date: \$2,000

Section J. Conclusions and Recommendations

Through evaluation and selection processes, including decision matrices and performance analyses, the team chose a VR-based emotion recognition system using avatars and facial landmarks, leveraging AI to process and interpret emotions in real-time.

The initial design concepts were assessed and refined through the engineering design process, with the use of computational models and iterative testing. The selection of a video-based experimental approach allowed us to test the emotion recognition system under controlled conditions, while the development of an AI tool in Unity (based on the FER2013 dataset) enabled the recognition of emotional states through facial expressions. Despite some challenges in the accuracy of the initial model, iterative improvements were made, and we are now approaching a prototype that can accurately recognize emotions with a processing time of less than one second per frame.

Recommendations for Future Work:

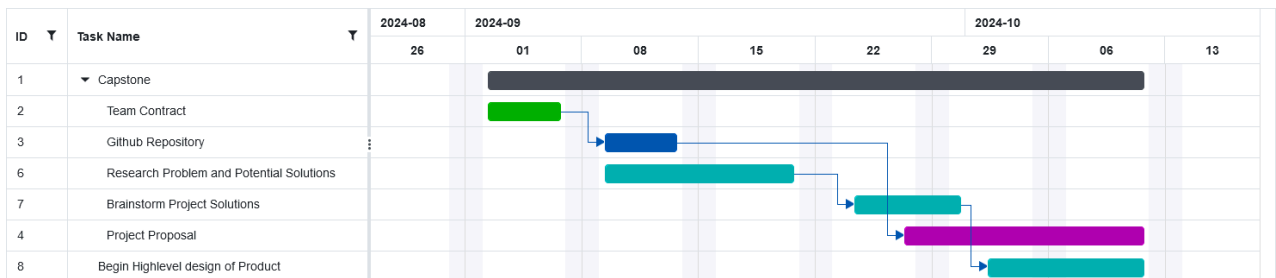
- Conduct a larger-scale human-subject experiment to assess the real-time performance of the emotion recognition system under varied conditions, including gameplay and different emotional stimuli.
- Implement the system with wearables to integrate physiological responses with AI-based facial expression recognition.
- Refine the AI algorithms by training the model on more diverse data and improving the accuracy and robustness of emotion detection.

Final Thoughts:

This project has made significant strides toward creating a VR-based emotion recognition system using AI, which provides a non-intrusive and scalable solution for real-time emotional feedback in virtual environments. The design has evolved through the engineering design process, overcoming various challenges and iterating to improve the model's accuracy and performance. While there are still areas for refinement, the current prototype has laid a solid foundation for future development, with clear paths for enhancement and potential commercial applications.

Future researchers and developers can build upon the work done in this project, expanding its capabilities and applications. The foundation laid here can lead to impactful advances in emotional intelligence technologies, especially in the growing fields of virtual reality, mental health, and human-computer interaction.

Appendix 1: Project Timeline



Appendix 2: Team Contract (i.e. Team Organization)

Step 1: Get to Know One Another. Gather Basic Information.

<i>Team Member Name</i>	<i>Strengths each member bring to the group</i>	<i>Other Info</i>	<i>Contact Info</i>
Aryan Rathi	I enjoy being punctual when it comes to assignments and deadlines. The sooner the better. I enjoy doing the most when it comes to my part of the assignment, expecting my teammates to do the same.	N/A talked with my group about my skillset!	rathia@vcu.edu
Philip Leake	I enjoy problem solving and excel at staying on top of work.	Talked with group	leakepa@vcu.edu
Youssef Bahloul	Encouraging discussion. Being proactive. Organizing and prioritizing tasks. Python.		bahloul@vcu.edu
Theus Frase	Some natural language processing and machine learning experience		frasecm@vcu.edu

<i>Other Stakeholders</i>	<i>Notes</i>	<i>Contact Info</i>
Kostadin Damevski	Meeting 12-1 every Wednesday. Both sponsor and Faculty Advisor	kdamevski@vcu.edu

Step 2: Team Culture. Clarify the Group's Purpose and Culture Goals.

<i>Culture Goals</i>	<i>Actions</i>	<i>Warning Signs</i>
Collaboration	Team members actively engage in open communication, share diverse perspectives, and leverage each other's strengths to achieve common goals. For example, during brainstorming sessions.	Communication becomes stunted and members work independently without seeking input or collaboration from others, leading to missed opportunities and misunderstandings.
Accountability	Team members take ownership of their responsibilities, meet deadlines, and support one another in achieving their goals. For example, when our team faces challenges, team members work together in order to solve the issues and ensure success.	Accountability is not there, leading to missed deadlines, finger-pointing, and a lack of progress on commitments, ultimately hindering our team's progress and success.

Innovation	The team fosters a culture of continuous improvement and involvement, where members encourage and welcome new ideas. For example, during problem-solving sessions.	Resistance to change or a fear of failure stifles creativity, and team members become hesitant to suggest or experiment with new ideas.
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Step 3: Time Commitments, Meeting Structure, and Communication

<i>Meeting Participants</i>	<i>Frequency Dates and Times / Locations</i>	<i>Meeting Goals Responsible Party</i>
Students Only	As Needed, On Discord Voice Channel	Update group on day-to-day challenges and accomplishments
Students Only	Wednesday at 2 in the library	Actively work on the project and update the plan for the week.
Students + Faculty advisor	Every Wednesday at 12 pm - 1pm in the second floor ERB.	Update faculty advisor and get answers to our questions. (Take notes during meeting; record the advisor's suggestions)

Step 4: Determine Individual Roles and Responsibilities

<i>Team Member</i>	<i>Role(s)</i>	<i>Responsibilities</i>
Youssef Bahloul	Project Manager	<ul style="list-style-type: none"> - Delegate tasks - Develop schedule - Run meetings
Philip Leake	Logistics Manager & Github Engineer	<ul style="list-style-type: none"> - Coordinates interactions - Lead in establishing contact - Obtaining information for the team - Documents meeting minutes - Manages facility and resource usage.
Theus Frase	Financial Manager	<ul style="list-style-type: none"> - Researches technical purchases and acquisitions - Conducts pricing analysis and budget justifications - Carries out team purchase requests - Monitors team budget.
Aryan Rathi	Systems/Test Engineer	<ul style="list-style-type: none"> - Analyzes Client initial design specification - Develops and recommends system architecture - Oversees experimental design, procedures and data analysis - Acquires data acquisition equipment and software - Establishes test protocols and schedules

		<ul style="list-style-type: none"> - Oversees statistical analysis of results - Leads presentation of experimental finding and resulting recommendations.
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Step 5: Agree to the above team contract

Team Member: Philip Leake *Signature: __Philip Leake__*

Team Member: Aryan Rathi *Signature: __Aryan Rathi__*

Team Member: Theus Frase *Signature: __Theus Frase__*

Team Member: Youssef Bahloul *Signature: __Youssef Bahloul__*

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