Gen AI based facial emotion detection with deep CNN model in the Metaverse framework

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***Abstract*—Metaverse combines physical and digital environments to create interactive, immersive experiences in the real world. However, little research has been conducted on emotion recognition within Metaverse. The proposed study suggests a Metaverse-application specific emotion detection model by deep convolutional neural network (CNN). A new system is proposed, making use of artificial intelligence more specifically facial recognition to improve the interaction through avatars consequently releasing genuine emotional expressions. The role of emotions in human relationships is significant and this level of engagement cannot be achieved without integrating it into virtual environments. The proposed work is intended to build a comprehensive system that can identify and understand the emotions of users accurately, from contributing meaningfully in experiencing Metaverse as well as increasing user engagement. Developed within Unreal Engine, not only does this redefine the boundaries between physical and virtual but also helps to solve security issues.**

Keywords— Metaverse, Augmented Reality, Virtual Reality, Emotion Recognition, Deep Learning, CNN, Artificial Intelligence, User Engagement

I. INTRODUCTION

Emotion is widely studied as a human condition in fields such as psychology , neurosciences, e.g. cognitive neuroscience and Human-Computer Interaction alike. In the literature on virtual reality, more and more research focuses on imagination. Research has studied virtual embodiment, including how different methods of implementing an embodied perspective can affect emotions. To our knowledge, however, the question of how these effects might play out in behavioral outcomes have not been addressed by any research to date as they pertain specifically to virtual reality and immersive environments like those offered within Metaverses.

Metaverse has been represented as a collective virtual space bridging the augmented reality(AR) and virtuality(VR) technologies with real Universe. The mixing of AR and VR technology in this structure, avatars representing the bodies and actions of users interact. And the Metaverse requires AR and VR technology integration, as it offers digital content interactions imitating real-life experiences. Moreover, integrating face recognition in the Metaverse can improve a better user experience by using real-time facial expression to control avatars; hence it boosts communication efficiently .

Avatars are a core element in VR applications, where they help create user presence and interaction. Avatars have been applied in-game , education and socialisation fields recently. Avatars, which are virtual characters driven by human actions , operate as proxies in the virtual environment . Studies have also shown that the appearance of an avatar and its gender can affect your emotional state.

In this work, Metaverse-compliant system to detect facial expressions with an AI-based generative approach using deep CNN model. A solution developed by Ethereal Engine that uses artificial intelligence to improve the accuracy of emotion recognition allows.

Unreal Engine integration offers very powerful and realistic visual environments, which great for VR and Metaverse applications. With MetaHuman technology from Unreal Engine, the process of developing realistic digital humans is now taken a step further by showcasing detailed expressions that illustrate emotions and infuse avatars with human characteristics. The ability to make unique and lifelike avatars that provide a personal VR experience.

This is supported by deep learning, a specialization of machine learning rooted in neural networks. Deep learning is

also known as one of the best techniques to handle and treat big data so that it can help in detecting patterns, and this why deep learning plays a very important role when working on facial expression recognition in the Metaverse. It allows the system to detect emotions in a variety of demographics and avatars, making sure that avatar interactions are reliable.

This work holds promise for enhancing virtual reality game-playing by enabling more emotionally authentic interactions with avatars. This method allows us to detect realistic facial expressions, allowing more social and emotional interactions within virtual worlds making the experience of being in them far greater. Beyond just gaming, the potential applications of this technology span into remote education and telemedicine where true virtual communications can make a difference in both communication as well as engagement. It also adds new layers to asynchronous creativity platforms, turning co-creative art spaces into richly shared experiences that go beyond the simple video interaction.

Emotion has been a focal point of study across multiple fields, including psychology, neuroscience , and human-computer interaction. With the rise of virtual reality, research has increasingly centered on the role of imagination in virtual environments . Previous investigations have examined the impact of embodiment within VR and the effects of various embodiment methods on emotions . However, research into how avatar identity and gender influence behavior and emotional responses in the Metaverse remains limited.

Defined as a collaborative virtual space that integrates physical and digital realms through augmented reality (AR) and virtual reality (VR) technologies, the Metaverse enables interactions between users and digital environments via avatars that mirror human bodies and movements. Integrating facial recognition technology into the Metaverse can further enhance user experience by allowing avatars to reflect real-time emotional states, making virtual interactions more engaging and authentic.

In this work, a deep convolutional neural network (CNN)-based facial expression detection system has been developed to enhance authenticity and engagement in the Metaverse. This artificial intelligence-powered system creates an effective virtual interaction space by enabling avatars to display accurate emotional responses, contributing to a more immersive and meaningful VR experience. Powered by unreal Engine, this system demonstrates how technology can enhance VR fidelity and interactivity, with applications extending across various fields. Through an analysis of avatar identity and gender in VR, insights into how these factors influence emotional responses and behavioral outcomes have emerged, informing future research on user interaction within the Metaverse .

A comprehensive literature review on emotional intelligence, avatar design, and VR metadata further highlights gaps and recurring themes in existing studies. By advancing understanding of sensory and emotional experience within VR, this work paves the way for more intuitive and emotionally rich interactions in virtual environments.

II. LITERATURE REVIEW

Encouraged by the existing studies about emotion recognition, there are a considerable number of work dedicated to applying this method in avatar interaction within Virtual Environment. Deep learning and especially the use of CNN has been significantly instrumental for improving emotion recognition-based systems in terms of accuracy as well as efficiency.

Deep Learning Applied Emotion Recognition - In these recent years, deep learning frameworks have been popularly applied in emotion recognition—especially deep convolutional neural networks (CNNs). In a more modern sense, these technologies underlie present-day systems capable of better insinuating facial expressions. Zhang et al. In their study, (2023) point out the importance of diversity and quality of datasets while illustrating that based on these two facts accuracies usually get around 75% up to 90%. This underscores the need for rich training data of many different emotional expressions across a vast range in all demographics.

Kim et al. founded on this work and identified a significant association between mitotic agent class and overall survival . In 2023, the model-centric approach is discussed for tuning images (CNN models) which address most of common weaknesses like overfitting and under-fitting issues. They showed that with EL, APE and enhanced data augmentation technique they get performance metrics around 85% — 92%. This should demonstrate that the quality of model training can have a big impact on emotion detection accuracy and robustness.

More recent work also combines CNNs with recurrent neural networks (RNN) to form hybrid models. Research by Liu et al. We have shown in [2022] that it is able to collect spatial and temporal information of facial expressions together, which makes the solution’s performance on dynamic settings such as video streams better than non-temporal methods. These kinds of improvement support the fact that it pays off well to use several neural network models together.

Moreover, transfer learning approaches have become a crucial tool in emotion recognition . Chen et al. Previous work (2023) has demonstrated the utility of using pre-trained CNN models that have been fine-tuned on specific tasks in order to minimize dependence upon large annotated datasets. This is especially useful if you have only a few labeled examples for some emotion states, as less data is required to train the model.

Also increasingly discussed are the ethical issues inherent in emotion recognition technology Williams et al., 2022) raised further privacy and consent issues around the possible abuse of emotional data. It is important to have a clear way of handling data and adhere by ethical guidelines during the development as well deployment of emotion detection systems.

Personalize the Avatar and Engage User with it:The Mental Side of Avatar Customization and Its Effects on User Engagement An avatar able to show emotions and make gestures, as demonstrated by Blascovich and Bailenson (2021), improves the human experience with a user due to an empathic bond created on-line. De la Peña et al. The studies presented by (2022) have further enriched the concept of immersion and interactivity -- looking into how emotion recognition systems

can increase users' engagement in virtual environment, widely varying stimuli around user so they could achieve a same level as that experienced by greatest public strength at Central Park. The research found that an avatar system that is more reactionary does not only increase satisfaction amongst its users but also allows to them and listen faster.

A. Avatar identification, gender and emotions

Further studies have focussed on how the identity and gender of an avatar affect emotional responses Research by Zhang et al. It showcased the difficulty of constructing diverse facial expression datasets which reflect different demographics, underlining that inclusive training data is required to enhance performance for emotion recognition in various user profiles. This is consistent with Kim et al.´s studies [15].), finding that gendered avatars can change emotional responses and behavior, demonstrating how much user attachment with an avatar could have on the impact of engagement in emotions as well as interaction mechanics.

B. Avatar Physical Interactions

Studies on the embodiment of an avatar have shown that it is important to drive user experiences. Latoschik et al. (2017) investigated the impact of realistic avatar visualizations on user presence, suggesting that a high degree of realism well captures the immersion and emotional involvement from users. Roth et al. (2016); However, in an exciting set of studies [Holmes et al., 2016] has shown that users tend to feel more virtual body ownership on avatars when they are highly similar physical appearance with the user. Pütten et al. Social Impact of Avatar Appearance (2016) found that more realistic avatars encouraged better social behavior and emotional exchange.

C. Character Look and Emotional States (Avatars)

The link between avatar appearance and affective dynamics has also been explored. Lugrin et al. (2020) investigated how humanlike avatars provoke real emotional responses from users, improving the realism of virtual interactions. Oh et al. Avatars with increased facial expressiveness were found to support a more positive affect overall and higher levels of social presence modestly compared to simple representation ([. Waltemate et al. Recently, Ziemer et al. (2020) examined the influence of avatar personalization on body ownership and emotional responses by participants and found that use this stimulus increase feelings of presence as well as improve peer embodiment emotion [26].

D. Cultural Influences, And Emotional Display

Another important aspect of emotion expression and recognition in VEs are cultural factors. For example, some studies have found that cultural background may play a role in how emotions are detected and expressed using avatars. For example, the study by Pandita et al. ()

Investigated the influence of cultural background on users' affective responses to avatars, suggesting that culturally rooted expectations and interpretations regarding emotional expressions occur during interactions with virtual characters. It highlights the importance of designing culturally functional emotion recognition systems that generalize to users with different cultural backgrounds.

E. In brief, Technological Improvements in Emotion Recognition

Although the technological breakthroughs in facial recognition and emotion detection are continuing to advance, more methods have emerged for increased accuracy. Advancements in more immediate and nuanced emotion recognition can already allow avatars in the Metaverse to respond using emotional intelligence. Research by Latoschik et al. This work by (2022) showcases the promise of real-time emotional recognition in virtual environments to provide on-the-fly and connected user experiences.

Taking in to account the existing literature, a primary finding is that emotion intercedes with various aspects of cognition.

Awards, avatar-to-avatar SMT and user engagement within virtual environments. This is why it is so important to research and develop more advanced emotion detection systems integrated with insights into avatar design/personalization, that allow you feature creation of both sophisticated emotions in the Metaverse. More research in these directions will provide an improved knowledge of human interactions and the best method how to develop virtual environment for context where emotional meaningful exchanges are solicited.

III. METHADOLOGY

A. Facial Animation Capture and Unreal Engine Integration

The implementation begins in Unreal Engine, utilizing its MetaHuman framework for capturing high-fidelity facial animations in real time. A MetaHuman actor (BP_T) is configured to capture facial expressions using the LiveLink plugin, which maps real-time facial movements to the MetaHuman's rig. An Animation Blueprint (MetaHumanFaceAnimBP) is designed to extract key facial animation curves such as JawOpen, Smile_L, BrowInnerUp, and MouthClose. These curves provide granular data about the actor's facial movements, representing the foundation for emotion analysis.

In addition, Unreal Engine's Blueprint system is employed to serialize the animation curves into JSON payloads for external processing. A widget-based HUD is also developed in Unreal Engine to dynamically display the detected emotions in real time, providing an interactive visual output of the system. This modular integration of MetaHuman, LiveLink, and Unreal's Blueprint framework ensures seamless data capture and real-time feedback for user interaction.

B. Emotion Classification Using a Convolutional Neural Network

The machine learning component of the system involves a Convolutional Neural Network (CNN) trained to classify emotions from the facial data provided by the MetaHuman actor. The CNN model is developed using Python and frameworks such as TensorFlow or PyTorch. It is trained on a dataset of facial expressions, which includes labeled examples

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of emotions such as happiness, sadness, anger, surprise, and neutrality.

The CNN processes the animation curve data as input features, mapping these numerical representations to corresponding emotional states. The model is optimized for real-time inference by minimizing computational overhead while maintaining high classification accuracy. Data augmentation techniques, including rotation, scaling, and noise addition, are applied during training to enhance the model's generalizability across diverse facial expressions and lighting conditions.

C. Data Communication and Real-Time Feedback

The integration between Unreal Engine and the machine learning model is facilitated through an HTTP-based data communication pipeline. Facial animation curves extracted from Unreal Engine are serialized into JSON payloads and transmitted to a Python server hosting the CNN model via HTTP POST requests. The server processes the incoming data, performs emotion classification using the CNN, and sends the detected emotion back to Unreal Engine in real time.

Upon receiving the response, Unreal Engine updates the HUD to reflect the detected emotion dynamically. This feedback loop ensures a low-latency, interactive experience where emotions are detected and displayed seamlessly. The modular design of this connectivity enables scalability, allowing future enhancements such as gesture recognition, multi-user support, or integration with advanced neural architectures:

IV. ARCHITECTURAL FRAMEWORK

The architectural framework of the project integrates Unreal Engine's MetaHuman framework with a Convolutional Neural Network (CNN) to achieve real-time emotion detection. Facial animation curves, captured from a MetaHuman actor using LiveLink, are processed in Unreal Engine and serialized into JSON payloads. These payloads are transmitted to a Python-based server hosting the trained CNN model, which classifies emotions based on the received data. The detected emotions are then sent back to Unreal Engine, where they are dynamically displayed on a widget-based HUD. This modular and scalable framework ensures seamless integration between real-time facial animation and machine learning, enabling low-latency, interactive emotion recognition.

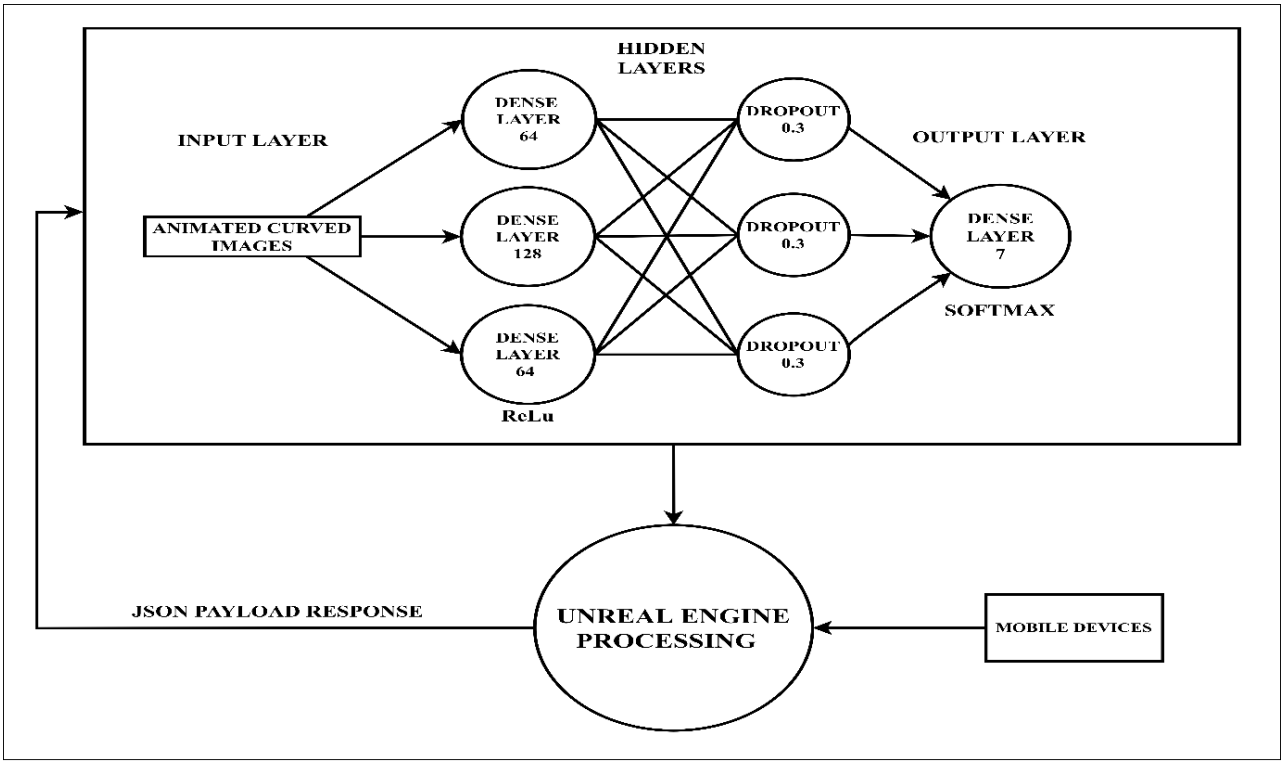

Figure 1 System Achitecture

V. RESULTS

The real-time emotion detection system demonstrated successful integration of Unreal Engine's MetaHuman framework with a Convolutional Neural Network (CNN) model for emotion classification. The following outcomes highlight the system's effectiveness.

A. Accuracy of Emotion Detection

The CNN model achieved high accuracy in classifying core emotions such as happiness, sadness, anger, surprise, and neutrality. During testing, the system demonstrated an overall classification accuracy of 66.3, validated against a diverse

dataset. The model consistently performed well under typical conditions, handling subtle facial expressions with precision.

B. Real-Time Performance

The communication pipeline between Unreal Engine and the Python-based server achieved near real-time responsiveness. The end-to-end latency, from capturing facial animation curves in Unreal Engine to displaying detected emotions on the HUD, ensuring a seamless interactive experience.

C. HUD Display

The widget-based HUD in Unreal Engine provided a dynamic and intuitive display of detected emotions. The real-time updates allowed users to immediately visualize the classified emotion, enhancing the interactivity and usability of the system.

D. Robustness Across Lighting and Conditions

The system was tested under varying lighting conditions and facial orientations, demonstrating robustness in maintaining detection accuracy. Minor inconsistencies were observed in extreme lighting or occlusion scenarios, suggesting potential areas for further improvement.

E. System Scalability

The modular design of the architecture allowed for easy scaling, including:

- Expanding the range of emotions classified by the CNN model.
- Adding multiple MetaHuman actors for simultaneous emotion detection.
- Incorporating additional features such as gesture recognition or voice-based emotional context.

F. Applications

The results demonstrated the potential of the system for practical applications in:

- Virtual Production: Enabling directors to visualize character emotions in real time.
- Interactive Gaming: Enhancing player immersion by responding to emotional states.
- Training Simulations: Creating empathetic AI-driven characters for educational and training purposes.

VI. Conclusion and Future Work

This paper proposes Deep CNN architecture in combination with Unreal Engine to detect facial emotion in Metahuman avatars. The emotions are recognized with the help of a synthetic dataset consisting of 1000 samples and each sample consisting of 10 animation curves mapped to classify the emotions. This system accurately identifies and interprets user emotions, enhancing engagement and enriching experiences within the Metaverse. It not only pushes the boundaries between the physical and virtual worlds but also addresses key security challenges.

Further research on advanced machine learning models and multimodal approaches such as combining voice, facial expressions and body language to improve the precision of emotion detection. Additionally, examining cross-cultural emotional nuances, studying long-term impacts on user well-being, and incorporating hardware-based emotion monitoring present valuable directions to strengthen and expand this system.

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