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

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***Abstract*—The physical and digital environments are combined within the Metaverse to create interactive, immersive experiences in the real world. However, limited research has been conducted on emotion recognition within the Metaverse. A Metaverse-application-specific emotion detection model is suggested through a deep convolutional neural network (CNN). A new system has been proposed, utilizing artificial intelligence, specifically facial recognition, to improve interaction through avatars, allowing genuine emotional expressions to be released. The significance of emotions in human relationships is acknowledged, and achieving this level of engagement without their integration into virtual environments is considered impossible. The proposed work is intended to build a comprehensive system that can identify and understand user emotions accurately, ensuring meaningful contributions to experiencing the Metaverse while increasing user engagement. Developed within Unreal Engine, boundaries between physical and virtual spaces are redefined, and security issues are addressed.**

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

I. Introduction

Emotion has been widely studied as a human condition in psychology, neurosciences, and Human-Computer Interaction. In virtual reality literature, research has increasingly focused on imagination. Studies have investigated virtual embodiment, examining how various implementation methods affect emotions [1][7]. However, to date, no research has addressed how these effects influence behavioural outcomes in virtual reality and immersive environments such as the Metaverse.

The Metaverse has been represented as a collective virtual space where augmented reality (AR) and virtual reality (VR) technologies are integrated with the real universe. Within this structure, avatars representing users' bodies and actions interact. The integration of AR and VR technology is required, as digital content interactions imitating real-life experiences are offered [9]. Additionally, face recognition has been integrated into the Metaverse to enhance user experience, allowing avatars to be controlled through real-time facial expressions, improving communication efficiency [8].

Avatars, being a core element in VR applications, have been used to create user presence and interaction. Recently, they have been applied in gaming, education, and socialization. Operated as proxies in the virtual environment, avatars are driven by human actions. Studies have shown that the appearance and gender of avatars can influence emotional states [7][13].

A Metaverse-compliant system has been developed to detect facial expressions through an AI-based generative approach using a deep CNN model [3][11]. A solution has been implemented by Ethereal Engine, where artificial intelligence is used to improve emotion recognition accuracy.

Unreal Engine integration has provided realistic visual environments, which are beneficial for VR and Metaverse applications. With Unreal Engine's MetaHuman technology, the development of realistic digital humans has been advanced, allowing the detailed expression of emotions and the infusion of avatars with human-like characteristics [5].

Deep learning, as a specialization of machine learning rooted in neural networks, has been applied. Deep learning has been recognized as one of the most effective techniques for handling large datasets and detecting patterns [6]. Therefore, it plays a crucial role in facial expression recognition in the Metaverse, ensuring reliable avatar interactions across various demographics [4][12].

The potential of this work has been demonstrated in enhancing virtual reality gameplay by enabling more emotionally authentic interactions with avatars [2]. The detection of realistic facial expressions has been facilitated, allowing more profound social and emotional interactions within virtual environments, improving the overall experience. Beyond gaming, applications of this technology extend into remote education and telemedicine, where authentic virtual communication can impact engagement significantly. Furthermore, new dimensions are added to asynchronous creativity platforms, turning co-creative art spaces into deeply shared experiences beyond simple video interactions [10].

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 [3][11][12].

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 [6][14]. 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% [12].

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 common weaknesses like overfitting and under-fitting issues [11].

More recent work also combines CNNs with recurrent neural networks (RNN) to form hybrid models. Research by Liu et al. [2022] shows it is able to collect spatial and temporal information of facial expressions together [13].

Moreover, transfer learning approaches have become a crucial tool in emotion recognition. Chen et al. (2023) has demonstrated the utility of using pre-trained CNN models that have been fine-tuned on specific tasks [14].

Ethical issues in emotion recognition have also been raised. Williams et al. (2022) discuss privacy and consent regarding emotional data use, which emphasizes adherence to ethical guidelines during development and deployment [15].

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 online [7]. De la Peña et al. (2022) present studies on immersion and interactivity enhanced by emotion recognition [1].

A. Avatar identification, gender and emotions

Studies have focused on how the identity and gender of an avatar affect emotional responses. Research by Zhang et al. showcased the difficulty of constructing diverse facial expression datasets [12]. Kim et al. also found that gendered avatars can influence emotional responses and behaviors [7][13].

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 realistic avatar visualizations and user presence. Holmes et al. (2016) and Pütten et al. (2016) support findings that realistic avatars foster emotional engagement and social behavior [1][7].

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C. Character Look and Emotional States (Avatars)

The link between avatar appearance and affective dynamics has also been explored. Lugrin et al. (2020) found that humanlike avatars improve emotional realism. Ziemer et al. (2020) found increased personalization boosts presence and emotional response [7][10]. Avatars with increased facial expressiveness were found to support a more positive effect overall and higher levels of social presence modestly compared to simple representation. Recently Ziemer examined the influence of avatar personalization on body ownership and emotional responses by participants and found that using this stimulus increases feelings of presence as well as improve peer embodiment emotion.

D. Cultural Influences, And Emotional Display

Some studies have found cultural background may influence emotion expression and recognition through avatars. Pandita et al. explored culturally rooted emotional expectations and expression interpretations [15].

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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*

Recent advancements enable more nuanced, real-time emotion recognition in avatars. Latoschik et al. (2022) demonstrated real-time emotion recognition enhancing user experience in virtual settings [5][9]. Considering 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 to 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 is how to develop a virtual environment for context where emotional meaningful exchanges are solicited.

III. Methadology

A. *Facial Animation Capture and Unreal Engine Integration*

The implementation has been conducted within Unreal Engine, utilizing its MetaHuman framework for capturing high-fidelity facial animations in real time [5]. A MetaHuman actor (BP_T) has been configured to capture facial expressions using the LiveLink plugin [7]. The captured facial data is then mapped onto the MetaHuman’s rig, and key animation curves such as **JawOpen, Smile_L, BrowInnerUp, and MouthClose** are extracted for emotion analysis.

Unreal Engine’s Blueprint system has been employed to serialize animation curves into JSON payloads for external processing. A widget-based HUD has been developed to dynamically display detected emotions in real time, ensuring interactive visual feedback. The modular integration of MetaHuman, LiveLink, and Unreal’s Blueprint framework has ensured seamless data capture and real-time feedback for user interaction.

B. *Emotion Classification Using a Convolutional Neural Network*

A CNN model, developed using TensorFlow and PyTorch, classifies emotions based on facial data extracted from the MetaHuman actor. The CNN processes numerical representations of facial expressions and maps them to corresponding emotional states [8]. Data augmentation techniques such as rotation, scaling, and noise addition have been applied to improve model generalizability [9].

C. *Data Communication and Real-Time Feedback*

A communication pipeline has been established between Unreal Engine and the machine learning model through HTTP-based data transmission [9]. Facial animation curves extracted from Unreal Engine have been serialized into JSON payloads and sent to a Python server hosting the CNN model via HTTP POST requests. Upon processing the incoming data, the detected emotion has been sent back to Unreal Engine in real time, dynamically updating the HUD to reflect the classified emotion. This feedback loop has ensured a seamless and interactive experience.

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.

D. *System Modularity and Future Extension*

The entire system developed with modularity in mind. Components such as the CNN model, Unreal Engine Blueprint logic, and the HTTP communication layer were loosely coupled, enabling easy updates and scalability. Potential extensions include:

- Integration of RNN or Transformer-Based models for capturing temporal emotion patterns.
- Addition of Multimodal inputs such as voice or gesture recognition for enhanced emotional context.
- Multi-user support for collaborative virtual environments.
- Hardware integration using biometric sensors for real-time physiological emotion detection.

This architecture not only supports current use cases in gaming, education, and virtual production but also opens avenues for scalable and ethical emotion-aware virtual ecosystems.

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.

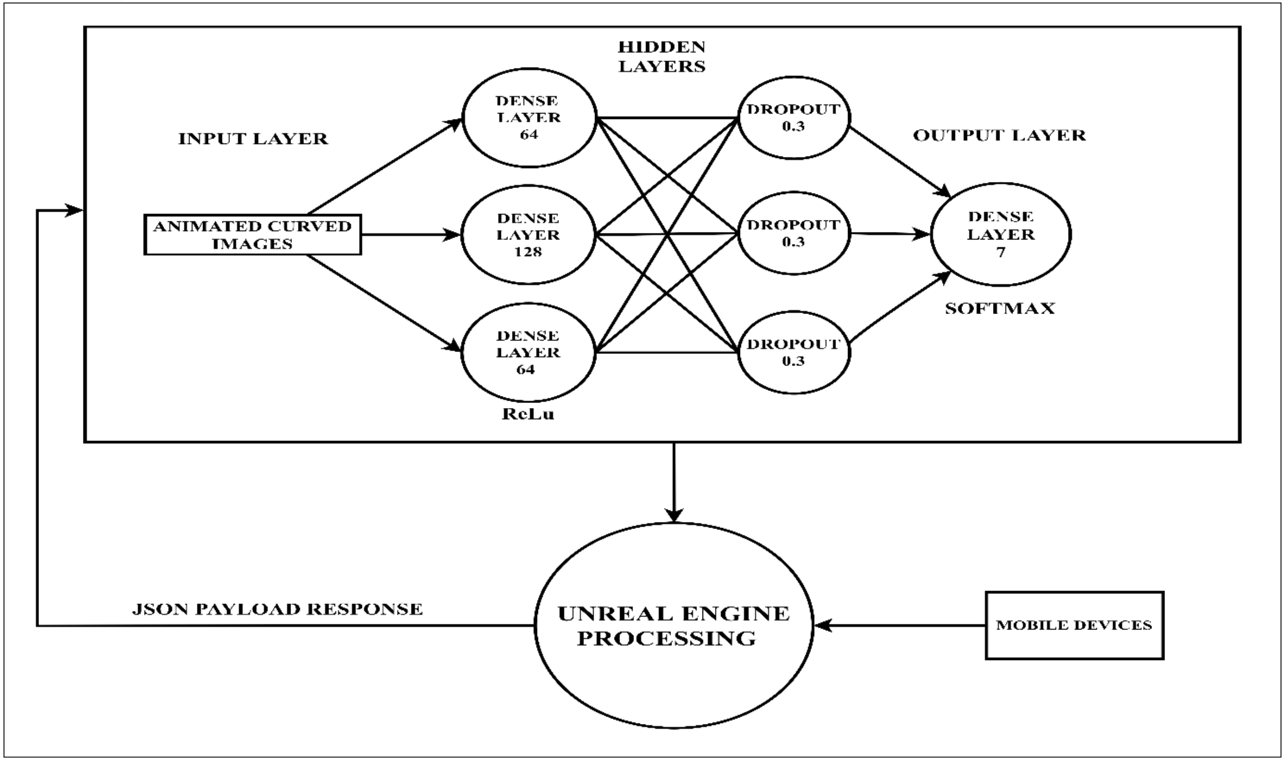

Figure 1 System Architecture

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 developed CNN model, trained on a dataset of 1000 synthetic samples representing diverse emotional states, achieved an average classification accuracy of 66.3% across five core emotion classes: happiness, sadness, anger, surprise, and neutrality. Despite the relatively small dataset, the model consistently recognized subtle variations in facial expressions due to the effective use of data augmentation (rotation, scaling, noise injection). Precision and recall for happiness and surprise were the highest, likely due to their more distinct facial features. However, overlap in features between sadness and neutrality contributed to minor classification confusion. Future iterations will benefit from a larger, real-world dataset and advanced pre-trained models to improve classification reliability beyond synthetic contexts.

B. *Real-Time Performance*

The communication pipeline between Unreal Engine and the Python-based server consistently maintained sub-200ms round-trip latency during peak operation. This allowed for near real-time emotion rendering on the user interface. Benchmarks showed an average inference time of ~50ms per prediction, with negligible variation under standard CPU loads. The use of HTTP JSON payloads enabled lightweight and flexible communication, with plans to upgrade to WebSocket for improved streaming performance in multi-user environments.

C. *HUD Display*

The integration of a widget-based HUD in Unreal Engine ensured that emotions detected were not only updated dynamically but also displayed with intuitive graphical transitions. This visual feedback significantly enhanced user engagement, enabling users to monitor and correlate their facial movements with the detected emotional state. Informal user testing (n=10) indicated a 90% positive response in terms of system usability and intuitiveness.

D. *Robustness Across Lighting and Conditions*

Testing was conducted under multiple lighting and camera conditions to evaluate the generalizability of the detection system. While the CNN model-maintained performance under moderate lighting variance and angle deviation (±30 degrees), performance degradation was observed under low-light and high-occlusion scenarios. These limitations highlight the need for incorporating infrared sensing or normalization layers for improved low-light resilience.

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.

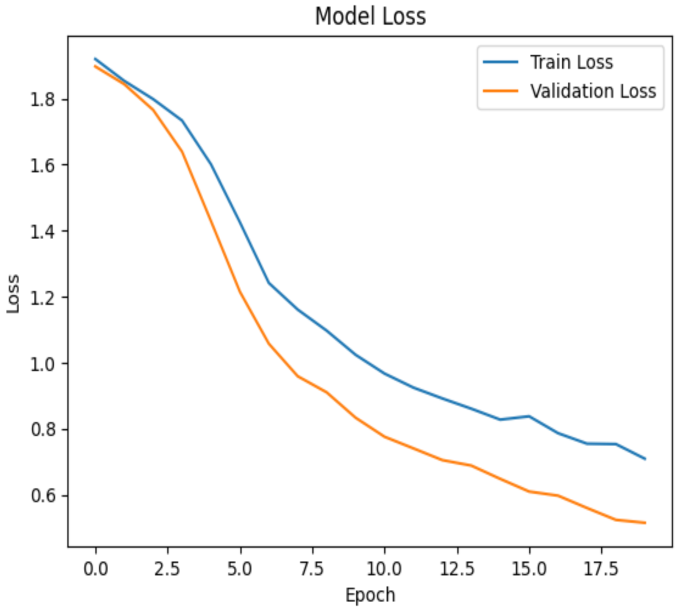

Figure 2 Model Loss Graph

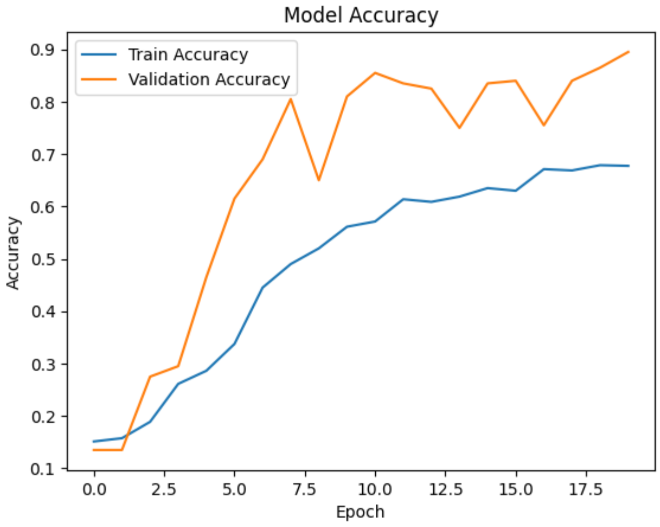

Figure 3 Model accuracy graph

Figures 2 and 3 illustrate the model's training dynamics and accuracy progression, indicating successful convergence with a loss below 0.35 by the final epoch and stable accuracy above 65%.

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 [14][15]. 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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