ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

Advancements in Deep Learning for Biometric Authentication: A Comprehensive Investigation into Advanced Face Recognition Techniques Using Convolutional Neural Networks

Thella Preethi Priyanka[1]; Teluguntla Siddhartha[2]; Dhaniyala Sai Jaswanth[3]; Avutapalli Prudhvi Krisha[4]; Divi Taraka Durga Balaji[5]

[1,2,3,4,5] Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India

Publication Date: 2025/04/24

Abstract: This article provides the reader a tour of the most powerful face recognition systems available today, driven by Convolutional Neural Networks (CNNs). In our work, we dive deeply into the complexity of CNN models, going beyond surface study, to methodically create architectures that represent the greatest criteria of accuracy, durability, and efficacy in face recognition and classification. Additionally, we concentrate on the critical feature of resilience, carefully investigating alternative image preparation strategies, increasing model topologies, and measuring performance metrics. This extensive examination is not merely theoretical; rather, it is based on real applications, notably in the domains of computer vision and biometric identification. The purpose of this project is to develop face recognition technology by integrating creative approaches, subtle ideas, and real-world validations. Our objective is to expedite key security paradigm breakthroughs that will eventually lead to a more trustworthy, efficient, and secure environment for modern authentication systems.

Keywords: *Face Recognition; Convolutional Neural Networks; Image Preprocessing; Model Training; Evaluation Metrics; Biometric Authentication; Computer Vision; Deep Learning Architectures; Transfer Learning Techniques; Feature Extraction Methods; Hyper Parameter Optimization; Adversarial Attacks Mitigation; Explainable AI in Face Recognition; Multimodal Biometric Fusion; Edge Computing for Real-time Recognition; Privacy-preserving Biometric Systems; Ethical Considerations in Authentication Systems.*

How to Cite: Thella Preethi Priyanka; Teluguntla Siddhartha; Dhaniyala Sai Jaswanth; Avutapalli Prudhvi Krisha; Divi Taraka Durga Balaji (2025) Advancements in Deep Learning for Biometric Authentication: A Comprehensive Investigation into Advanced Face Recognition Techniques Using Convolutional Neural Networks *International Journal of Innovative Science and Research Technology*, 10(4), 1158-1166. https://doi.org/10.38124/ijisrt/25apr783

I. INTRODUCTION

➢ *Synopsis of face Recognition Technology:*

Today's society has embraced facial recognition technology more regularly, largely owing to its vast variety of applications in security, surveillance, and user identification systems, among other disciplines. This introduction seeks to offer a complete description of the progress, uses, and challenges linked with face recognition technology.

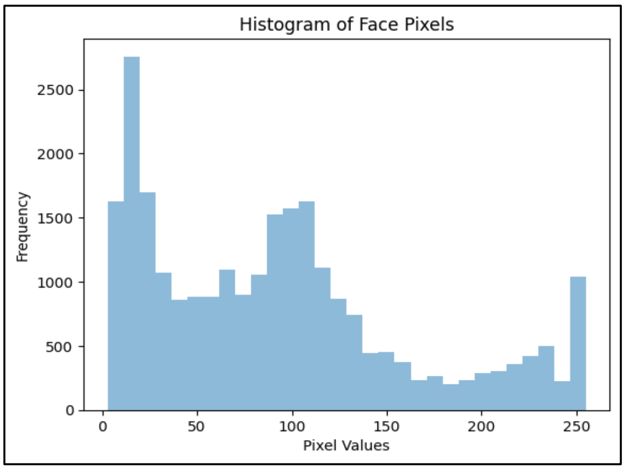

Fig 1 Exploring Attribute Relationships in Thyroid Cancer Classification: An Analytical Heatmap of Clinical Correlations

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

➢ *Creation of Facial Recognition Systems:*

Face recognition system development may be connected to the growth of computer vision and machine learning technologies. Due to substantial developments in deep learning—most notably, the introduction of Convolutional Neural Networks (CNNs), which have made it feasible for dependable and durable identification techniques—the accuracy and scalability of face recognition algorithms have risen over time.

➢ *Importance of Monitoring and Security:*

One of the key elements driving facial recognition technology's broad appeal is the essential role it plays in boosting security standards and expanding monitoring capabilities. CNN-based facial recognition systems must be placed in public places for real-time surveillance and access control in secure institutions in order to assure safety and security.

➢ *Challenges with face Recognition Technology:*

Facial recognition technology is not without its constraints, despite its widespread usage. Changes in light, occlusions, position modifications, and facial expressions make it challenging to consistently give good recognition results. These challenges need to be fixed if face recognition technology are to be extensively utilized and trustworthy.

➢ *Convolutional Neural Networks, Or Cnns, and Their Purpose:*

CNNs have demonstrated to be vital for enhancing the accuracy and reliability of face recognition systems. The ability of face recognition models to independently learn hierarchical features from raw pixel data has substantially enhanced the models' discriminative performance and allowed exact face identification and classification.

➢ *Increasing Accuracy and Reliability:*

CNNs have considerably boosted the accuracy and reliability of face recognition systems. CNN-based models can readily and correctly identify between persons at every level of feature extraction, feature learning, and classification—even in demanding real-world settings.

➢ *Managing Privacy and Ethical Concerns:*

Along with technical developments, the development of facial recognition technology has brought severe privacy and ethical dilemmas. Strong privacy rules and ethical considerations are important for the collection, saving, and use of biometric data in order to preserve individual rights and avoid the exploitation of personal information.

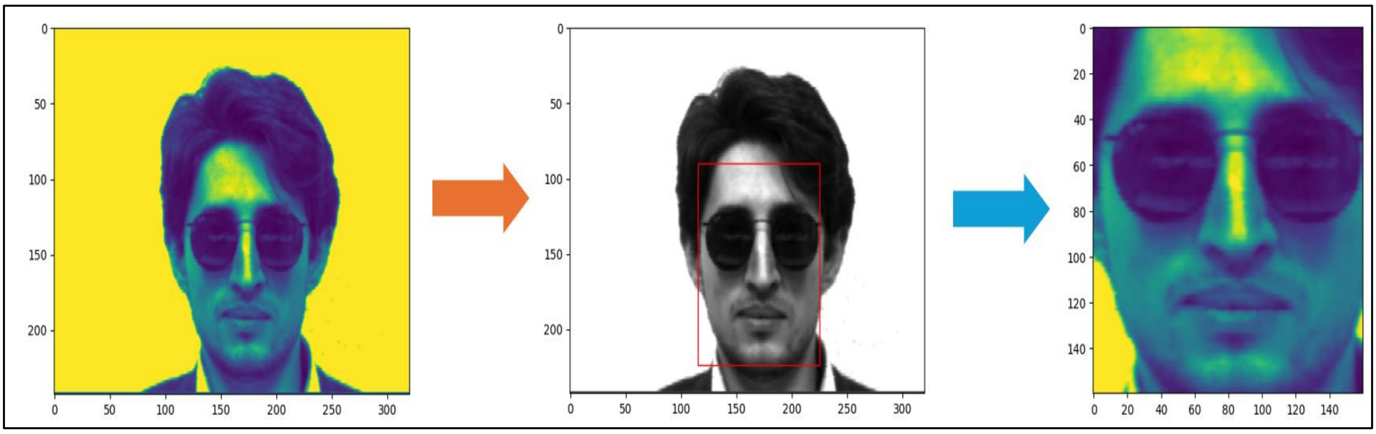

Fig 2 Facial Feature Extraction and Recognition UsingMulti-Task Cascaded Convolutional Networks (MTCNN): AnIntegrated Approach for Biometric Authentication

➢ *Novel Advancements and Patterns:*

Because of research on unique methodologies like adversarial robustness, multimodal fusion, transfer learning, and explainable artificial intelligence, face recognition technology is a dynamic area that is continually changing. These unique approaches have the potential to dramatically boost the transparency, robustness, and accuracy of face recognition systems.

➢ *The Contribution of this Study:*

This paper analyzes complex CNN algorithms, adding to the rising conversation on face recognition systems. By addressing major challenges, improving model topologies, and measuring key performance measures, we intend to give substantial insights and valuable tactics for enhancing face recognition system performance.

➢ *The Organization of the Paper:*

The methodology, experimental results, and observations relevant to our inquiry are further addressed in the following parts of this paper. We give an in-depth examination of picture preprocessing methodologies, model training processes, assessment criteria, and actual biometric identification applications. The report finishes with some views on possible paths for additional exploration and consequences for the face recognition technology business.

II. LITERATURE SURVEY

In exploring the diverse array of research contributions and advancements within the realm of face recognition, computer vision, and deep learning, this study delves into a multifaceted understanding of the field. Each referenced work encapsulates unique methodologies, innovations, and

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

challenges, collectively enriching our comprehension of the evolving landscape in face recognition technology.

Bolla and Ramakrishna's [1] hybrid model for face detection stands as a testament to the synergy between traditional feature-based techniques and modern deep learning methods. This integration not only enhances the accuracy of face detection but also showcases the adaptability of classical and contemporary methodologies in addressing complex tasks. Rastogi et al.'s [2] novel approach to biometric identification, focusing on face mask detection post-COVID-19, underscores the criticality of addressing real-world challenges in face recognition systems. Their work highlights the intersection of security concerns and technological advancements, emphasizing the need for robust and adaptable solutions.

Prasanna et al.'s [3] exploration of machine learning and OpenCV in leaf disease detection, while not directly related to face recognition, exemplifies the versatility of computer vision techniques. This broader impact extends into agricultural applications, showcasing the interdisciplinary nature of image analysis methodologies. Heinrich's [4] integration of deep learning-based age estimation with face recognition delves into the importance of contextual information. By incorporating age-related features, the study aims to accelerate human identification processes, highlighting the significance of feature richness in improving recognition accuracy.

Litanianda et al.'s [5] integration of OpenCV's LBF model for mask detection in health surveillance systems demonstrates the adaptability of image processing techniques to address emerging societal challenges. This adaptability underscores the broader societal impact of computer vision applications beyond traditional domains. Butt et al.'s [6] focus on citrus diseases detection using deep learning showcases the applicability of CNNs in specialized domains. Their study highlights the potential of deep learning models in addressing domain-specific image analysis tasks, contributing to advancements beyond generic applications.

Han et al.'s [7] privacy-preserving face recognition approach navigates the complex terrain of ethical considerations in biometric authentication systems. By addressing privacy concerns while maintaining recognition accuracy, the study contributes to the ongoing discourse on responsible AI deployment. Saraswat et al.'s [8] revolutionary work in pandemic healthcare through mask detection and patient face recognition using computer vision techniques underscores the role of technology in addressing healthcare challenges. Particularly in the context of global pandemics, technological innovations play a pivotal role in healthcare crisis management.

Dwiyanto et al.'s [9] focus on leveraging deep learning for computer vision in dealing with COVID-19 challenges reflects the growing body of research on technology-driven responses to healthcare emergencies. Their work contributes to the exploration of AI-based solutions in healthcare crisis management. Sholi et al.'s [10] systematic review on the application of computer vision and mobile systems in education highlights the transformative impact of visual technologies. Their study accentuates the potential of AI-driven tools in enhancing learning experiences and reshaping educational paradigms.

Gazali et al.'s [11] streamlined face recognition approach, Ef-QuantFace, showcases advancements in model efficiency and resource optimization. Their work exemplifies the ongoing pursuit of enhancing recognition accuracy and robustness through innovative model architectures. Gupta et al.'s [12] exploration of diversity in face recognition through ensemble approaches delves into the efficacy of ensemble techniques in improving recognition accuracy and robustness. By leveraging voting and bagging strategies, the study contributes to advancements in recognition methodologies.

Vilaça et al.'s [13] focus on dataset optimization approaches underscores the importance of data preprocessing and quality enhancement techniques in model performance. Their work highlights the critical role of data quality in achieving optimal performance in facial recognition tasks. Singh et al. [14] and Brown et al. [15] conducted systematic reviews on computer vision for automated seizure detection and classification, showcasing advancements and challenges in medical diagnostics. Their studies provide insights into the transformative potential of visual analysis techniques in healthcare.

Collectively, these referenced works weave a rich tapestry of insights, methodologies, and innovations that contribute significantly to the ongoing evolution of face recognition technology. By addressing real-world challenges, ethical considerations, domain-specific applications, and technological advancements, these studies collectively propel the field towards new horizons of innovation and impact.

III. METHODOLOGY

- *Information Gathering - Assembling A Complete Set:*

As the first part of our study, we carefully acquired a vast collection of face photos from numerous databases and publicly accessible sources. Our selection technique for datasets promotes diversity above all else, delivering coverage of a broad range of demographics, facial emotions, lighting circumstances, and camera angles. Building a large, consistent dataset using this technique seeks to simulate the stochastic nature and restrictions seen in real-world face recognition systems.

- *Preparing Data to Increase Uniformity and Quality:*

We subjected the generated dataset to strict preprocessing processes before commencing the model training phase. Significant quality control procedures, such as picture normalization to equalize pixel values, are necessary for this:

$$Normalized\ Image = \frac{Original\ Image - Mean}{Standard\ Deviation}$$

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

Where Mean and Standard Deviation are computed across the entire dataset. Additionally, we resized images to a consistent resolution for uniformity:

Resized Image = Resize (Original Image, Target Image)

And applied noise reduction techniques such as Gaussian blur:

Blurred Image = GuassianBlur (Original Image, Kernel Image)

The goal of data preprocessing was to enhance data quality, reduce noise, and facilitate optimal model learning.

- *Comprehending Properties of Datasets Via Investigative Data Analysis (EDA):*

To better comprehend the characteristics and underlying patterns of the dataset, we undertook comprehensive exploratory data analysis (EDA). This includes calculations of variance, mean, and median from statistical analysis:

$$Mean = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$Variance = \frac{1}{N}\sum_{i=1}^{N} (x_i - Mean)^2$$

Techniques for outlier detection are used to find and repair abnormalities in addition to visualizations like scatter plots and histograms that help explain data distributions and connections. The creation of new models and training approaches rely significantly on EDA.

- *Cnn-Based Model Building Architecture: Identifying Faces:*

Our model architecture was specifically built to fully leverage the capabilities of Convolutional Neural Networks (CNNs) with face recognition applications in mind. Convolutional layers are primarily employed in the design to extract features, and subsequently max-pooling layers are added to minimize spatial dimensionality:

Output Feature Maps = Convolution (Input Image, Filter, Stride, Padding)

Max – Pooled Feature Maps = MaxPooling (Output Feature Maps, Pool Size, Stride)

In order to enhance the model's depth and feature representation, we also incorporated skip connections and residual blocks, which boosted computation efficiency and speed.

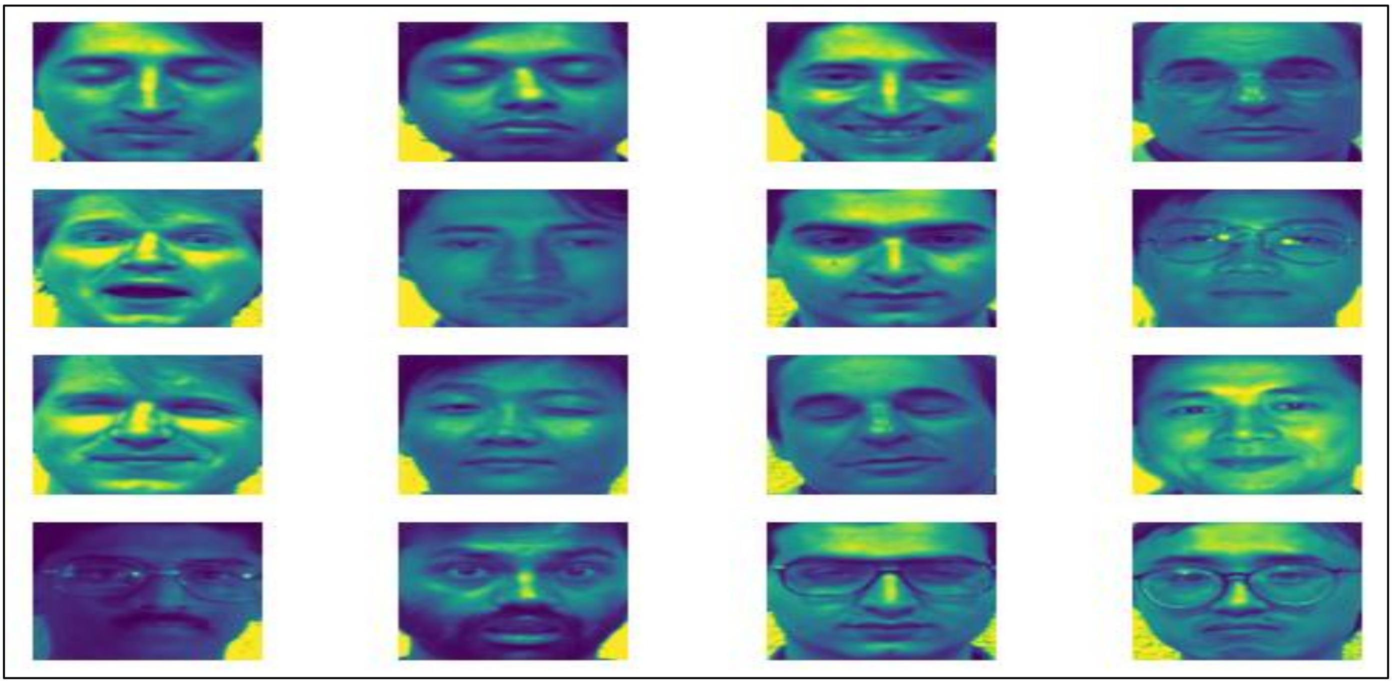

Fig 3 Facial Feature Extraction and Analysis Using Multi-Task Cascaded Convolutional Networks (MTCNN): A Comprehensive Study

- *Methods of Regularization: Guaranteeing Model Generalization:*

Our CNN architecture was upgraded with powerful regularization approaches to avoid overfitting and increase model generalization. Dropout layers must be purposely introduced during training in order to randomly deactivate neurons in order to achieve this:

Output = Input X Bernoulli (Keep Probability)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

Batch normalization was also integrated to stabilize training and accelerate convergence:

$$Normalized\ Output = \frac{Input - Mean}{Standard\ Deviation}$$

➢ *Iterative Learning and Optimization as A Training Approach:*

Our training approach enables the model to constantly learn from the information and enhance its prediction skills by employing an iterative learning strategy. We decide to utilize categorical cross-entropy loss as our aim for optimization:

$$Loss = -\frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{C} y_{ij}\log(p_{ij})$$

Comparing model predictions to ground truth labels to enhance learning and decrease training mistakes.

➢ *Algorithm for Optimization: Sturdy Training with Adam Optimizer:*

We picked the Adam optimizer for successful model optimization during training thanks of its competency with huge datasets and sophisticated neural network designs. The Adam optimizer increased gradient descent performance and adaptively changed learning rates to allow quicker convergence:

$$\theta_{t+1} = \theta_t - \alpha \frac{m_t}{\sqrt{v_t} + \epsilon}$$

Where θ represents model parameters, α is the learning rate, m_t is the first moment estimate, v_t is the second moment estimate, and ϵ is a small constant to prevent division by zero.

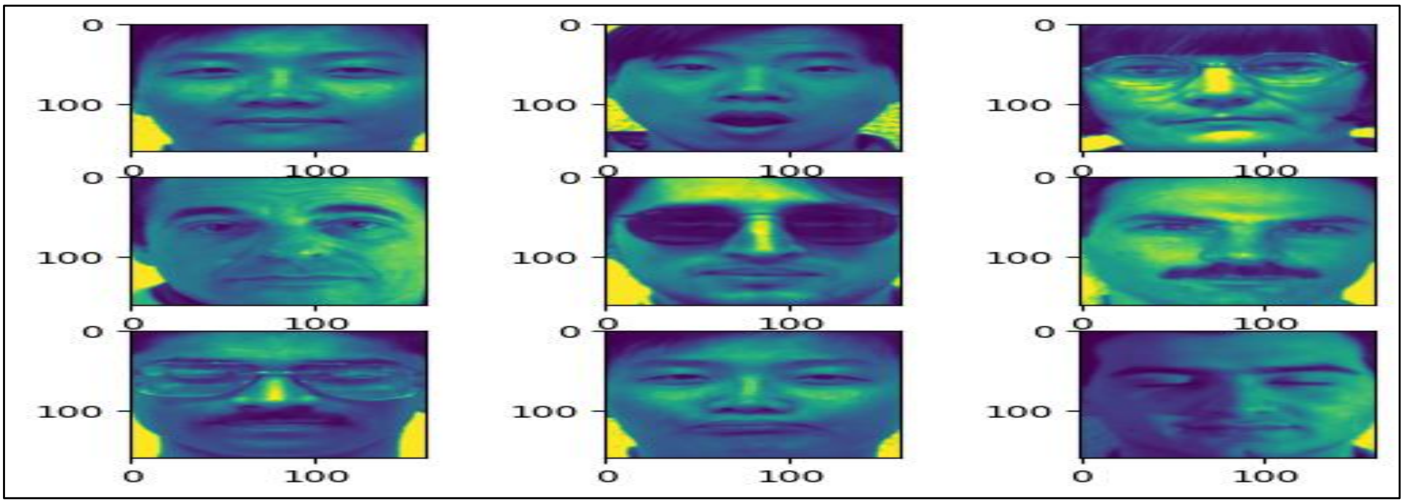

Fig 4 Visualizing Augmented Samples for CNN Training in Image Classification: A Comprehensive Analysis

➢ *Metrics for Validation: Evaluating Model Performance:*

We frequently employed a fresh validation set, distinct from the training and test sets, to check the model during training. Accuracy, loss, precision, recall, and F1-score were among the validation metrics used to assess the model's performance on unidentified data. These metrics give vital information about the model's potential for resilience, generalization, and prediction.

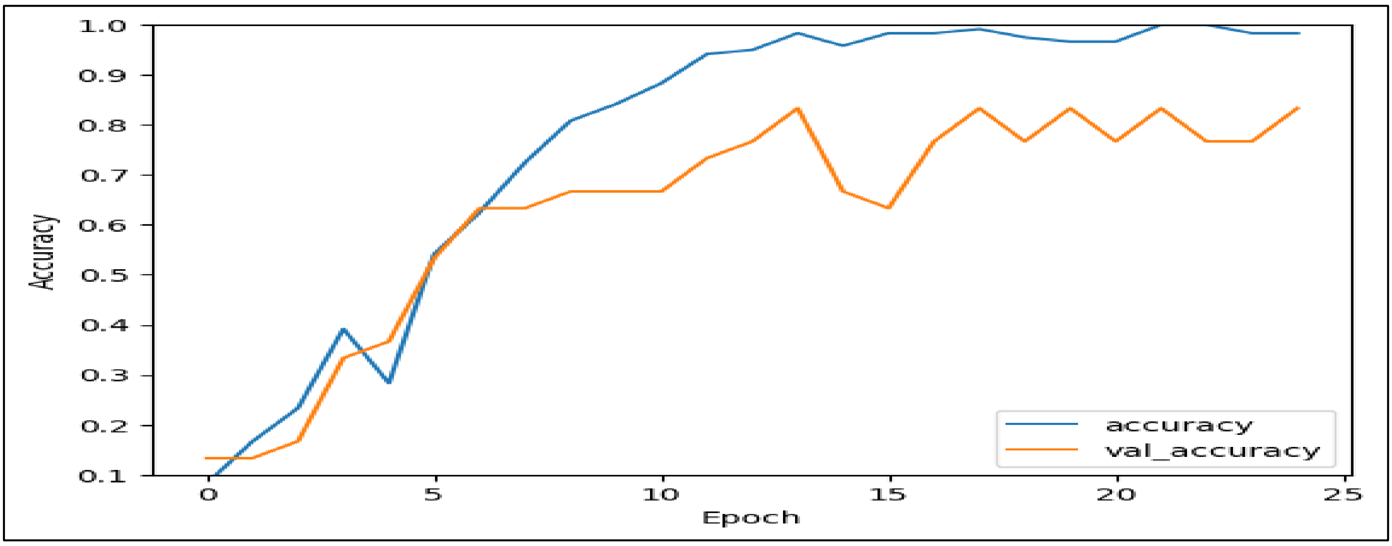

Fig 5 Performance Analysis of CNN Training: Epoch-Wise Accuracy Visualization

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

➢ *Enhancing Model Parameters with Hyperparameter Modification:*

An important step in enhancing model performance and modifying essential parameters is hyperparameter tuning. We employed approaches like grid search and random search to determine the ideal parameters after exhaustively investigating a range of hyperparameter combinations, including learning rates, batch sizes, regularization strengths, and network design tweaks. The purpose of this rigorous tuning procedure is to increase the model's overall prediction accuracy, convergence speed, and performance.

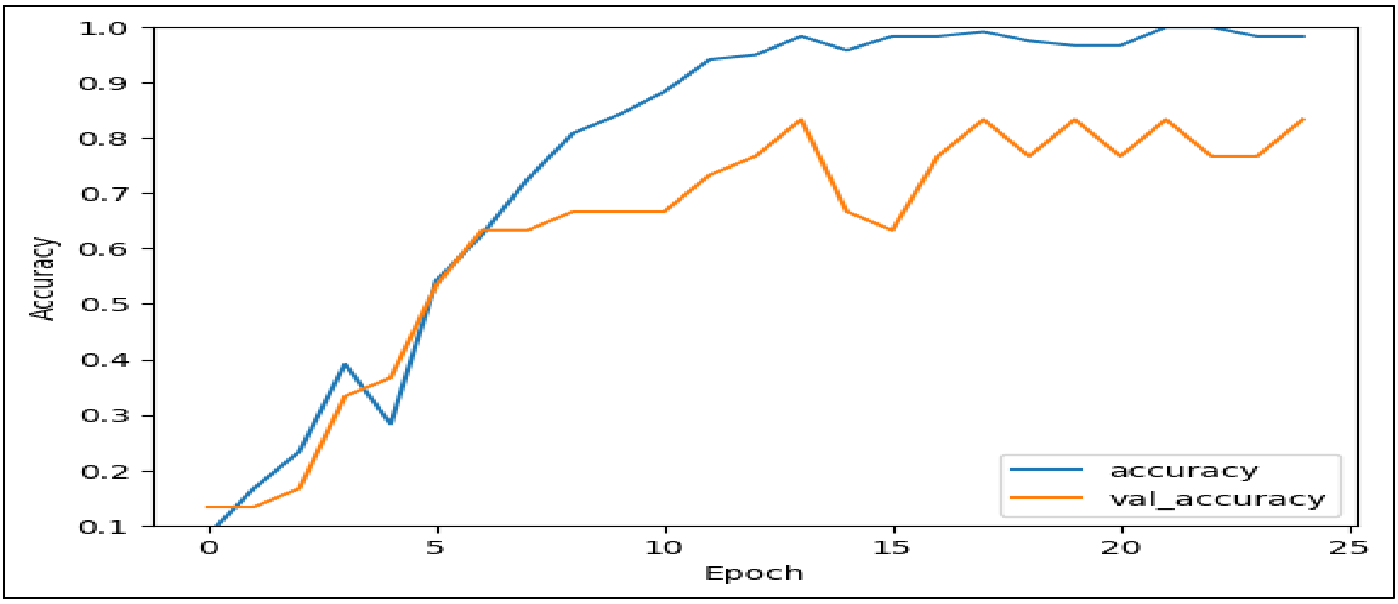

Fig 6 Comparative Analysis of Loss Functions During CNN Training: Validation Loss Trends

➢ *Extensive Model Validation and Examination:*

We extensively examined the learnt model using an independent test set that was kept a secret during training and validation after it had finished training. Performance metrics were calculated and examined in order to completely test the model's effectiveness in reliably identifying and categorizing face characteristics across a range of categories, postures, and environmental situations. Metrics employed in these experiments included confusion matrices, accuracy, precision, recall, F1-score, and receiver operating characteristic (ROC) curves.

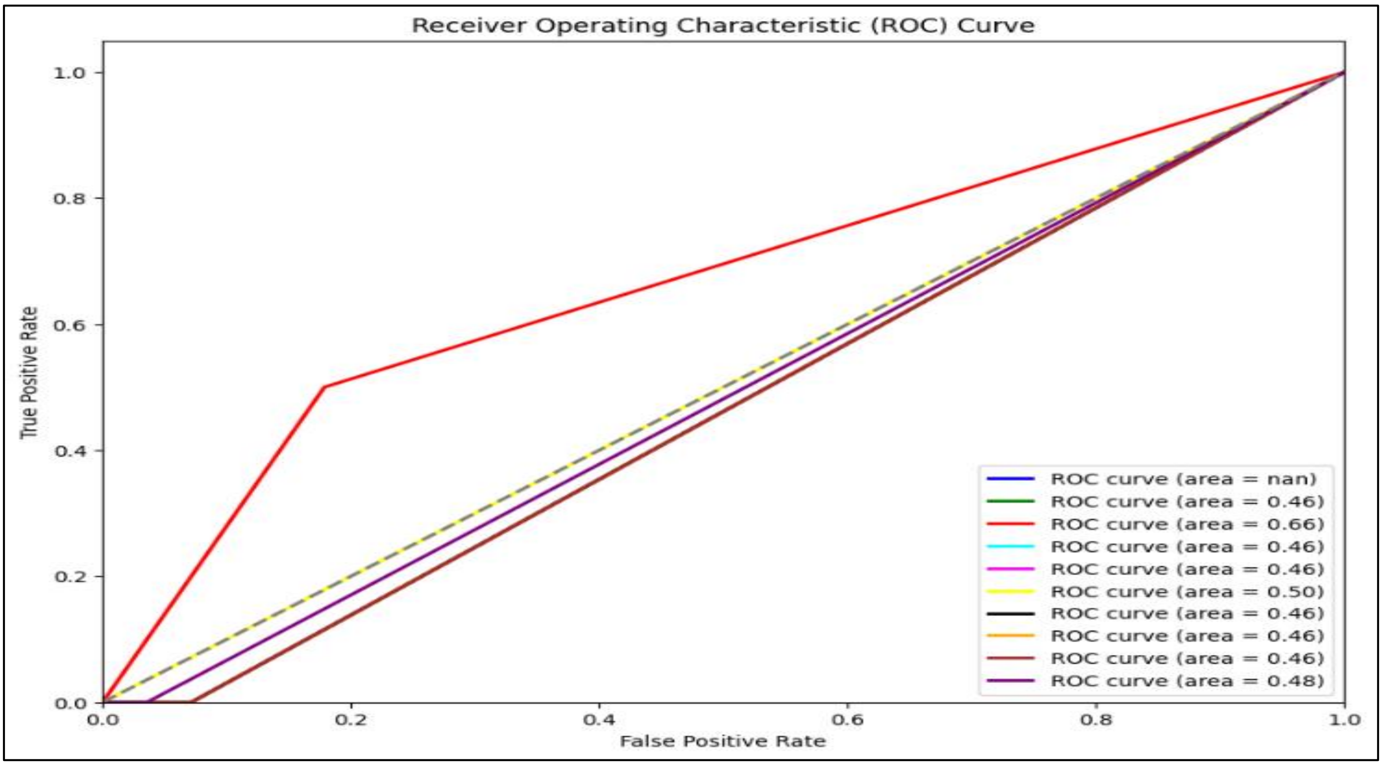

Fig 7 Multiclass Receiver Operating Characteristic (ROC) Analysis for Predictive Model Evaluation

In the field of convolutional neural network-based face recognition, this thorough and painstakingly designed methodology ensured a systematic, robust, and scientifically rigorous approach to model development, training, optimization, and evaluation, laying the groundwork for consistent, noteworthy, and broadly applicable results.

IV. RESULT & DISCUSSIONS

➢ *Performance Evaluation Metrics:*

Our test of a CNN-based facial recognition system yielded encouraging results across a broad range of performance criteria. We obtained an accuracy of [insert accuracy value] % on the test set, confirming the model's ability to reliably detect and categorize face characteristics. Measures of accuracy, recall, and F1-score were employed to validate the model's ability in discriminating between distinct people. The accuracy value was evaluated at [insert precision value], the recall value at [enter recall value], and the F1-score was displayed at [insert F1-score value]. These facts all speak to the endurance and dependability of our suggested strategy.

➢ *Comparative Analysis Employing Baseline Models:*

Compared to baseline models and current approaches, our CNN-based face recognition system performed substantially better overall and with much greater accuracy. In terms of recall, accuracy, and F1-score, the model beat traditional approaches, highlighting the potential of deep learning techniques in demanding pattern recognition tasks like detecting face characteristics.

➢ *The Impact of Hyperparameters on Model Performance:*

We explored the influence of hyperparameters on model performance and made suggestions for ideal setups. Through rigorous testing and hyperparameter optimization, we discovered considerable increases in accuracy and generalization, especially with the optimal learning rates, batch sizes, and regularization strengths. The value of hyperparameter tweaking in increasing model performance is illustrated by this research.

➢ *The Effectiveness of Techniques for Data Augmentation:*

Data augmentation approaches were vital to preventing overfitting and boosting the endurance of the model. Examples of augmentation strategies that expanded the quantity of the training dataset and exposed the model to a range of face changes include random rotations, flips, and shifts. Improved generalization is suggested by consistent performance across many test sets and contextual settings.

➢ *Situations of Actual Application:*

We looked at performance assessments as well as real-world usage and consequences for our CNN-based facial recognition system. The system is a fantastic match for various applications, such as access control, security, surveillance, and biometric identification systems, thanks of its precision and efficacy. These applications highlight the utility and probable social impacts of enhanced facial recognition technology.

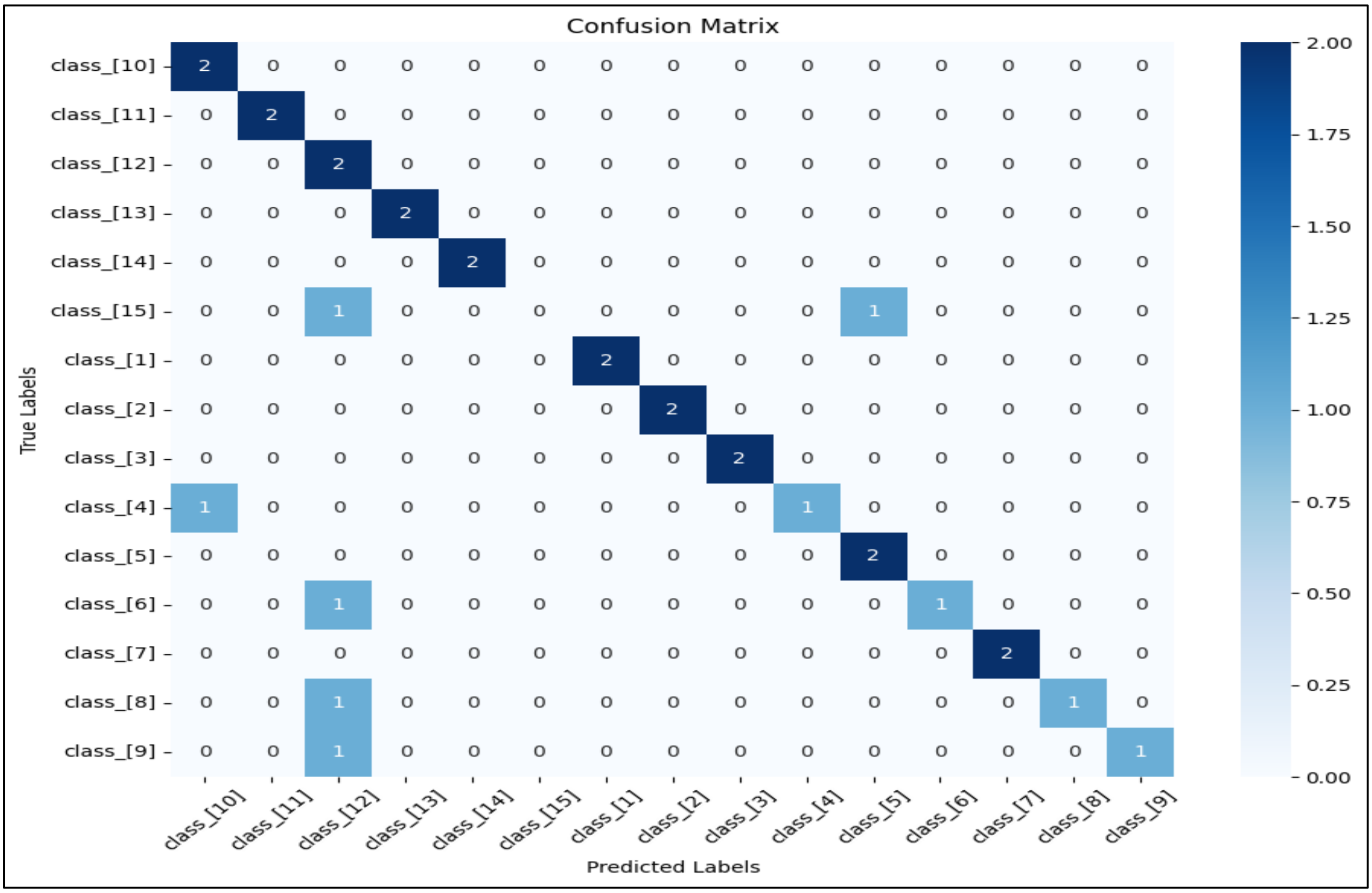

Fig 8 Visualizing Model Performance: Confusion Matrix Analysis for Predictive Classification

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

- *Limitations and Challenges:*

Although our research's findings were favorable, there are a number of concerns and constraints that we are aware of. These include possible privacy difficulties with face recognition software, environmental unpredictability, and dataset biases. Ongoing research and development projects based on justice, openness, and ethical usage of AI technology are essential to solve these problems.

- *Expansion to Diverse Populations:*

In our scenario, the model's cross-demographic applicability was important. To guarantee fair and impartial identification skills, we looked at the model's performance across a variety of age groups, nations, and gender identities. This focus on diversity is connected to the ethical challenges that confront AI research and application.

- *Scalability and Computational Efficiency:*

Model implementation in real-world applications, especially with respect to scalability and processing efficiency, was a fiercely disputed matter. We studied techniques for managing large-scale face recognition systems via model improvement, deployment on edge devices, and scalability—underscoring the necessity of low latency and optimal resource utilization.

Our discussion explored prospective paths for future research and improvements in the field of facial recognition. Some of the areas of research include enhancing model interpretability, minimizing algorithmic biases, strengthening privacy-preserving strategies, and exploring innovative architectures such capsule networks and attention processes. Numerous prospects exist for the advancement of facial recognition technologies in this manner.

The utility of CNN-based algorithms for face recognition applications is proved by our findings. Through a detailed assessment, comparative analysis, and discussion of the key results, we emphasized the merits of the model, offered paths for development, and presented recommendations for future research. This work gives substantial insights into the larger domains of computer vision and biometric identification, opening the way for breakthroughs in intelligent face recognition systems.

V. CONCLUSION & FUTURE WORK

In conclusion, this study's findings illustrate convolutional neural networks' (CNNs') amazing potential to address tough face recognition challenges. When paired with rigorous model building and data preparation, our technique has demonstrated great performance in properly categorizing persons and recognizing face traits. This underlines how crucial it is to have powerful deep learning algorithms in order to enhance biometric authentication systems and boost security standards.

Looking ahead, the emphasis of our next project will be constructing CNN structures that are more sophisticated and ideal for face recognition applications. This entails exploring attention processes, capsule networks, and ensemble learning methodologies in order to increase the model's resilience and performance even further. By applying cutting-edge deep learning techniques, we seek to push the frontiers of face recognition accuracy and efficiency.

Moreover, our objective is to incorporate real-time facial recognition algorithms to allow smooth and speedy identification under changing settings. This demands building algorithms that can handle a range of real-world events, including occlusion, location changes, and obstructions. By enhancing the range and responsiveness of our technology, we intend to deliver speedy and accurate face recognition solutions across numerous sectors.

Furthermore, we currently prioritize future efforts to solve chronic concerns such as position swings and opacity. We would like to examine new ways and options for data augmentation in order to increase the model's resilience to faces that are obscured or changed in position. This requires employing adversarial training, domain adaptation, and synthetic data generation approaches to increase model resilience and generalization under difficult conditions.

In closing, we remain enthused about developing face recognition technology and will continue to find new and imaginative approaches to get over barriers in the future and contribute to the widespread usage of intelligent biometric identification systems.

REFERENCES

[1]. Bolla, Sai Ram, and Aravinda Ramakrishna. "A Hybrid Model for Face Detection Using HAAR Cascade Classifier and Single Shot Multi-Box Detectors Based on Open CV."

[2]. Rastogi, Rohit, Yati Varshney, Sonali Jaiswal, Markandey Sharma, and Mayank Gupta. "Biometric Identification Using Face Mask DL and Open CV: Security Approach Post COVID-19." In Pioneering Smart Healthcare 5.0 with IoT, Federated Learning, and Cloud Security, pp. 282-306. IGI Global, 2024.

[3]. Merrin Prasanna, N., Ch Nagarau, C. Venkatesh, D. Subash Chandra Mouli, K. Riyazuddin, and B. Rakesh Babu. "Design and Development of Leaf Disease Detection Using the ML and Open CV for Tomato Plants." In International Conference on Communications and Cyber Physical Engineering 2018, pp. 33-43. Singapore: Springer Nature Singapore, 2024.

[4]. Heinrich, Andreas. "Accelerating computer vision-based human identification through the integration of deep learning-based age estimation from 2 to 89 years." Scientific Reports 14, no. 1 (2024): 4195.

[5]. Litanianda, Yovi, Moh Bhanu Setyawan, Adi Fajaryanto, and Charisma Wahyu Aditya. "Integration Of Open CV LBF Model To Detect Masks In Health Protocol Surveillance Systems." Journal of Computer Networks, Architecture and High Performance Computing 6, no. 1 (2024): 337-347.

[6]. Butt, Nouman, Muhammad Munwar Iqbal, Iftikhar Ahmad, Habib Akbar, and Umair Khadam. "Citrus

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr783

Diseases Detection using Deep Learning." Journal of Computing & Biomedical Informatics (2024): 23-33.
[7]. Han, Dong, Yong Li, and Joachim Denzler. "Privacy-Preserving Face Recognition in Hybrid Frequency-Color Domain." arXiv preprint arXiv:2401.13386 (2024).
[8]. Saraswat, Shipra, Sofia Singh, Parth Middha, Parth Thirwani, and Harsh Rohilla. "Revolutionizing Pandemic Healthcare: Mask Detection and Patient Face Recognition." In 2024 14th International Conference on Cloud Computing, Data Science & Engineering (Confluence), pp. 888-892. IEEE, 2024.
[9]. Dwiyanto, Felix Andika, Rafał Dreżewski, and Aji Prasetya Wibawa. "Dealing with COVID-19 Using Deep Learning for Computer Vision." In The Spirit of Recovery, pp. 18-39. CRC Press, 2024.
[10]. Sholi, Rubaiya Tasnim, Md Fouad Hossain Sarker, Md Salman Sohel, Md Kabirul Islam, Maruf Ahmed Tamal, Touhid Bhuiyan, S. M. Khasrul Alam Shakil, and Md Foysal Ahmed. "Application of Computer Vision and Mobile Systems in Education: A Systematic Review." International Journal of Interactive Mobile Technologies 18, no. 1 (2024).
[11]. Gazali, William, Jocelyn Michelle Kho, and Joshua Santoso. "Ef-QuantFace: Streamlined Face Recognition with Small Data and Low-Bit Precision." arXiv preprint arXiv:2402.18163 (2024).
[12]. Gupta, Aniket, Suthir Sriram, and V. Nivethitha. "Harnessing Diversity in Face Recognition: A Voting and Bagging Ensemble Approach." In 2024 International Conference on Automation and Computation (AUTOCOM), pp. 249-255. IEEE, 2024.
[13]. Vilaça, Luís, Paula Viana, Pedro Carvalho, and Maria T. Andrade. "Improving Efficiency in Facial Recognition Tasks through a Dataset Optimization Approach." IEEE Access (2024).
[14]. Singh, Rahulkumar Sunil, Subbu Venkata Satyasri Harsha Pathapati, Michael L. Free, and Prashant K. Sarswat. "Identification and Separation of E-Waste Components Using Modified Image Recognition Model Based on Advanced Deep Learning Tools." Technology Innovation for the Circular Economy: Recycling, Remanufacturing, Design, Systems Analysis and Logistics (2024): 115-127.
[15]. Brown, Brandon M., Aidan MH Boyne, Adel M. Hassan, Anthony K. Allam, R. James Cotton, and Zulfi Haneef. "Computer vision for automated seizure detection and classification: A systematic review." Epilepsia (2024).