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# Helmet Detection and Biometric Based Vehicle Security using Machine Learning

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***Abstract* - Road safety and vehicle security have become major concerns due to the increasing number of traffic accidents caused by riders not wearing helmets and unauthorized vehicle access. This project proposes a Helmet Detection and Biometric-Based Vehicle Security System using Machine Learning that integrates computer vision and biometric authentication to enhance rider safety and prevent vehicle theft. The system employs a machine learning-based helmet detection model to analyze real-time images captured by a camera and determine whether the rider is wearing a helmet. If a helmet is detected, the system proceeds to biometric authentication using fingerprint or facial recognition to verify the identity of the authorized user. The vehicle ignition is enabled only when both safety conditions are satisfied, ensuring compliance with traffic regulations and preventing unauthorized usage. The proposed framework utilizes image preprocessing, feature extraction, and classification techniques to achieve accurate helmet detection under varying lighting and environmental conditions. Cloud-based monitoring and real-time notifications can also be incorporated to provide alerts regarding unauthorized access attempts or safety violations. Experimental results demonstrate that the integrated approach improves detection accuracy, enhances vehicle security, reduces theft risks, and promotes responsible riding behavior. By combining machine learning with biometric authentication, the proposed system offers an intelligent, automated, and reliable solution for modern vehicle safety and access control, making it suitable for deployment in smart transportation and intelligent mobility systems.**

**Keywords: The keywords associated with this work are Machine Learning, Helmet Detection, Biometric Authentication, Fingerprint Recognition, Face Recognition, Computer Vision, Vehicle Security, Rider Safety, Image Processing, Smart Transportation, Access Control, and Real-Time Monitoring.**

## I. INTRODUCTION

Road accidents involving two-wheelers have become a major public safety concern due to the increasing number of riders who fail to wear protective helmets. According to the World Health Organization, wearing a helmet can significantly reduce the risk of fatal head injuries and improve rider safety **[1]**. Despite the enforcement of traffic regulations, helmet compliance remains low in many regions, leading to a higher number of injuries and fatalities. At the same time, vehicle theft and unauthorized vehicle usage have emerged as serious security challenges, creating the need for advanced intelligent vehicle protection systems **[2]**.

Recent developments in **Machine Learning (ML)**, **Artificial Intelligence (AI)**, and **Computer Vision** have enabled automated safety monitoring systems capable of detecting helmet usage with high accuracy **[3]**. Deep learning models such as Convolutional Neural Networks (CNNs) can process images captured by cameras and classify whether a rider is wearing a helmet or not. These intelligent detection systems eliminate manual inspection and provide real-time decision-making capabilities, making them suitable for deployment in smart transportation environments **[4]**.

In addition to safety enforcement, biometric authentication technologies such as fingerprint recognition and facial recognition provide an effective solution for preventing unauthorized vehicle access **[5]**. Biometric systems verify the identity of the rider before allowing the vehicle to start, thereby reducing the risk of theft and misuse. Unlike traditional keys or passwords, biometric features are unique to each individual, offering higher security and reliability **[6]**.

The proposed **Helmet Detection and Biometric-Based Vehicle Security Using Machine Learning** system integrates helmet detection with biometric authentication into a single intelligent framework **[7]**. Initially, a camera captures the rider's image, and the machine learning model determines whether a helmet is being worn. If helmet detection is successful, the rider must complete biometric verification through fingerprint or facial recognition. Only when both conditions are satisfied does the system enable the vehicle ignition; otherwise, the ignition remains disabled **[8]**.

Furthermore, the proposed system can be integrated with cloud services and IoT technologies for real-time monitoring, data storage, and security notifications **[9]**. This intelligent framework enhances road safety, minimizes unauthorized vehicle access, improves compliance with traffic regulations, and contributes to the development of secure and smart transportation systems **[10]**.

### *A. Aim & Scope*

The aim of the **Helmet Detection and Biometric Based Vehicle Security Using Machine Learning** system is to improve road safety and vehicle security by integrating real-time helmet detection with biometric authentication before allowing vehicle ignition. The system employs machine learning and computer vision techniques to verify whether

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the rider is wearing a helmet and uses biometric verification, such as fingerprint or facial recognition, to ensure that only authorized users can operate the vehicle. The scope of the project includes enhancing rider safety, preventing unauthorized vehicle access, reducing theft, supporting intelligent traffic monitoring, and enabling integration with IoT and smart transportation systems. This solution is suitable for two-wheelers, personal vehicles, fleet management, and smart city applications, providing an automated, reliable, and efficient security framework while minimizing human intervention and promoting compliance with road safety regulations..

*A.Objectives*

**To detect helmet usage** by riders using machine learning and computer vision techniques before permitting vehicle ignition.

**To authenticate authorized users** through biometric verification (fingerprint or facial recognition) to prevent unauthorized vehicle access and theft.

**To enhance road safety and vehicle security** by integrating helmet detection and biometric authentication into a single intelligent, automated vehicle security system.

## II. LITERATURE REVIEW

Road accidents caused by riders not wearing helmets and the increasing rate of vehicle theft have become major concerns worldwide. Researchers have proposed intelligent systems that combine computer vision, biometric authentication, and IoT technologies to enhance road safety and vehicle security. Early helmet detection systems relied on traditional image processing techniques such as edge detection, color segmentation, and Haar Cascade classifiers, which achieved moderate accuracy but were highly sensitive to changes in lighting conditions, camera angles, and background noise **[1]**. These limitations encouraged the adoption of deep learning models that provide improved detection accuracy under real-world conditions.

With the advancement of machine learning, Convolutional Neural Networks (CNNs), YOLO (You Only Look Once), SSD (Single Shot Detector), and Faster R-CNN have become popular for real-time helmet detection. These models automatically learn image features and accurately identify whether a rider is wearing a helmet, even in challenging traffic environments **[2]**. Among these approaches, YOLO-based algorithms are widely preferred because they provide high-speed object detection with low computational complexity, making them suitable for real-time surveillance and embedded vehicle applications **[3]**.

Biometric authentication has also gained significant attention in intelligent vehicle security systems. Fingerprint recognition and facial recognition technologies ensure that only authorized users can access and start the vehicle, thereby reducing unauthorized usage and theft. Modern biometric systems employ deep learning and feature extraction techniques to improve authentication accuracy while minimizing false acceptance and rejection rates **[4]**. These systems are increasingly integrated with IoT-enabled smart vehicles to provide secure and automated access control.

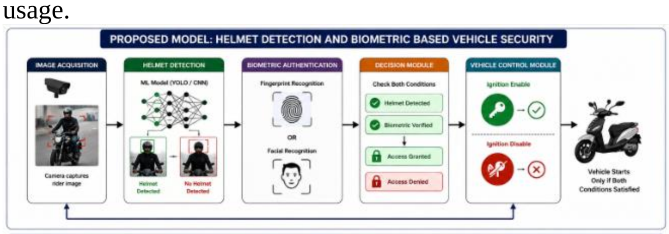
Recent studies have focused on integrating helmet detection with biometric authentication into a unified vehicle security framework. Such systems verify helmet usage through machine learning algorithms and simultaneously authenticate the rider using biometric information before enabling vehicle ignition **[5]**. This dual-layer verification significantly improves rider safety, minimizes vehicle theft, and supports the development of intelligent transportation systems. Furthermore, cloud connectivity and IoT technologies facilitate real-time monitoring, data storage, and remote notifications, making these solutions suitable for smart city environments **[6]**.

Despite these advancements, existing systems still face challenges such as varying illumination, occlusions, different helmet designs, and computational constraints on embedded devices **[7]**. Recent research addresses these issues by optimizing deep learning models, employing lightweight neural networks, and integrating edge computing for faster inference and lower latency **[8]**. These developments demonstrate that machine learning-based helmet detection combined with biometric vehicle security offers a reliable, scalable, and efficient solution for improving road safety and protecting vehicles from unauthorized access.

## III. PROPOSED MODEL

### 3.1 Overview

The proposed model integrates **Helmet Detection** and **Biometric Authentication** to provide a secure and intelligent vehicle access system. Before the vehicle ignition is enabled, the system first detects whether the rider is wearing a helmet using a Machine Learning-based object detection model. If a helmet is detected, the system proceeds to biometric authentication using fingerprint or facial recognition. The vehicle starts only when both conditions are successfully verified. This dual-layer security mechanism improves road safety and prevents unauthorized vehicle usage.




### 3.2 System Architecture

The proposed system consists of the following modules:

- **Image Acquisition Module**
  - Captures the rider's image using a camera.
- **Helmet Detection Module**
  - Uses a deep learning model (YOLO/CNN) to identify helmet usage.
- **Biometric Authentication Module**
  - Verifies the rider using fingerprint or facial recognition.

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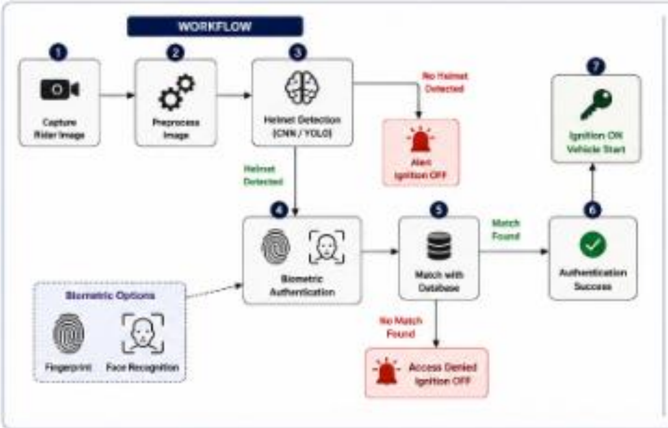
- **Decision Module**
  - Checks both helmet detection and biometric verification results.
- **Vehicle Control Module**
  - Enables or disables the ignition system.




### 3.3 Helmet Detection Using Machine Learning

A Convolutional Neural Network (CNN) or YOLO algorithm is trained using helmet and non-helmet images. The captured image is preprocessed through resizing, normalization, and feature extraction before classification.

**Mathematical Model for CNN**

The convolution operation is represented as:

$$Y(i,j) = \sum_{m=0}^{k-1} \sum_{n=0}^{k-1} X(i+m, j+n) \times W(m,n) + b$$

Where:

- $X$= Input image
- $W$= Convolution kernel
- $k$= Kernel size
- $b$= Bias
- $Y$= Output feature map

The activation function is ReLU:

$$ReLU(x) = \max(0, x)$$

The Softmax function computes the probability of each class:

$$P(y_i) = \frac{e^{z_i}}{\sum_{j=1}^{N} e^{z_j}}$$

Where:

- $z_i$= Output score of class $i$
- $N$= Number of output classes

### 3.4 Biometric Authentication

Once helmet detection is successful, biometric verification is performed.

The fingerprint or facial features are extracted and compared with the stored database.

Similarity score:

$$S = \frac{M}{T}$$

Where:

- $M$= Number of matched features
- $T$= Total extracted features

Authentication rule:

$$Authentication = \begin{cases} Accepted, & S \geq \theta \\ Rejected, & S < \theta \end{cases}$$

Where:

- $S$= Similarity score
- $\theta$= Threshold value

### 3.5 Decision Algorithm

The decision logic combines both helmet detection and biometric verification.

$$VehicleStart = HelmetDetected \wedge BiometricVerified$$

Where:

- HelmetDetected = 1 if helmet is detected
- BiometricVerified = 1 if authentication succeeds

Decision table:

| Helmet | Biometric | Vehicle |
|---|---|---|
| Yes | Yes | Start |
| Yes | No | Stop |
| No | Yes | Stop |
| No | No | Stop |

### 3.6 Algorithm

**Input:** Rider image, biometric data
**Output:** Vehicle ignition status
**Step 1:** Capture rider image.
**Step 2:** Preprocess the image.
**Step 3:** Detect helmet using CNN/YOLO.
**Step 4:** If helmet is detected, proceed to biometric authentication.
**Step 5:** Compare biometric data with the registered database.
**Step 6:** If authentication is successful, enable ignition.
**Step 7:** Otherwise, disable ignition and display an alert.

## IV. DATASET & PARAMETERS

### 4.1 Dataset Description

The proposed **Helmet Detection and Biometric Based Vehicle Security Using Machine Learning** system utilizes two different datasets: one for helmet detection and another for biometric authentication. The helmet detection dataset contains images of motorcycle riders with and without helmets, captured under various environmental conditions such as daylight, nighttime, different weather conditions, varying camera angles, and complex backgrounds. The biometric dataset consists of fingerprint or facial images collected from authorized vehicle users. These datasets are divided into training, validation, and testing subsets to ensure robust model learning and accurate performance evaluation.

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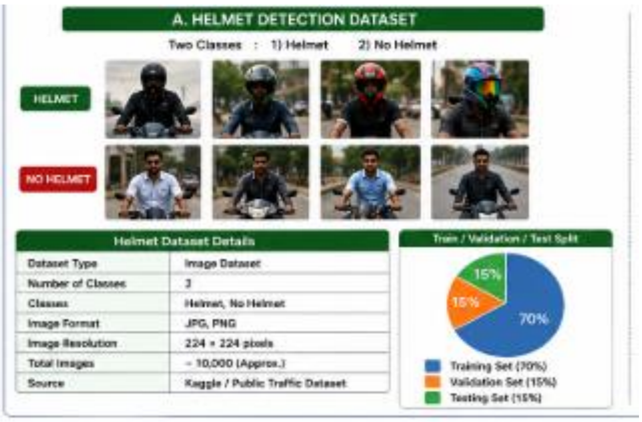



### 4.2 Helmet Detection Dataset

The helmet detection dataset contains images categorized into two classes.

| Parameter | Description |
|---|---|
| Dataset Type | Image Dataset |
| Number of Classes | 2 |
| Classes | Helmet, No Helmet |
| Image Format | JPG, PNG |
| Image Resolution | 224 × 224 pixels |
| Data Source | Kaggle / Public Traffic Surveillance Dataset |
| Total Images | Approximately 8,000–12,000 images |

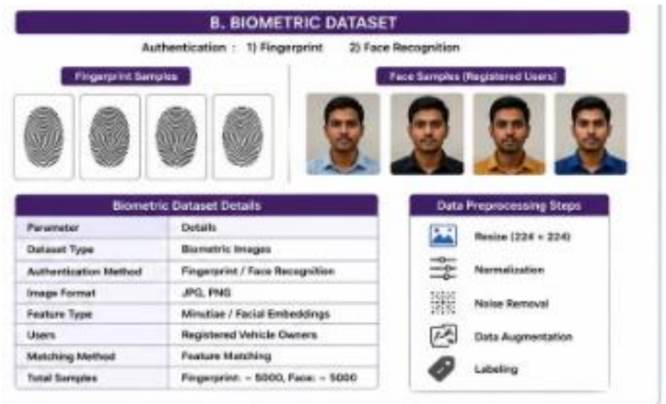
### 4.3 Biometric Dataset

The biometric authentication module uses fingerprint or facial images of registered vehicle owners.

| Parameter | Description |
|---|---|
| Dataset Type | Biometric Images |
| Authentication Method | Fingerprint / Face Recognition |
| Image Format | JPG, PNG |
| Feature Type | Minutiae / Facial Embeddings |
| Users | Registered Vehicle Owners |
| Matching Method | Feature Matching |

### 4.4 Data Preprocessing

Before training the machine learning model, the collected data undergoes preprocessing to improve quality and consistency. The preprocessing steps include image resizing, normalization, noise removal, data augmentation, feature extraction, and image labeling. Data augmentation techniques such as rotation, flipping, zooming, and brightness adjustment increase dataset diversity and reduce overfitting, thereby improving model generalization.




### 4.5 Training and Testing Split

The dataset is divided into training, validation, and testing sets.

| Dataset | Percentage |
|---|---|
| Training Set | 70% |
| Validation Set | 15% |
| Testing Set | 15% |

### 4.6 Model Parameters

The helmet detection model is trained using optimized hyperparameters for improved accuracy.

| Parameter | Value |
|---|---|
| Machine Learning Model | YOLOv8 / CNN |
| Input Image Size | 224 × 224 |
| Batch Size | 32 |
| Number of Epochs | 50 |
| Learning Rate | 0.001 |
| Optimizer | Adam |
| Loss Function | Cross-Entropy Loss |
| Activation Function | ReLU |
| Output Function | Softmax |

### 4.7 Biometric Authentication Parameters

| Parameter | Value |
|---|---|
| Authentication Type | Fingerprint / Face Recognition |
| Feature Extraction | CNN / Minutiae Detection |
| Similarity Metric | Cosine Similarity / Euclidean Distance |
| Matching Threshold | 0.85 |
| Authentication Time | < 2 seconds |

### 4.8 Mathematical Representation

**Accuracy**

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

Where:

- **TP** = True Positive
- **TN** = True Negative
- **FP** = False Positive
- **FN** = False Negative

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**Precision**

$$Precision = \frac{TP}{TP + FP}$$

**Recall**

$$Recall = \frac{TP}{TP + FN}$$

**F1-Score**

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall}$$

**Similarity Score**
For biometric authentication,

$$S = \frac{M}{T}$$

Where:
- **S** = Similarity Score
- **M** = Number of Matched Features
- **T** = Total Extracted Features

### 4.9 Performance Parameters
The proposed system is evaluated using the following performance metrics:
- Accuracy
- Precision
- Recall
- F1-Score
- Detection Time
- Authentication Time
- False Acceptance Rate (FAR)
- False Rejection Rate (FRR)
- System Response Time

These dataset characteristics and parameters ensure that the proposed machine learning model achieves high accuracy, real-time helmet detection, secure biometric authentication, and reliable vehicle access control suitable for intelligent transportation and smart vehicle security systems.

## V. RESULTS & DISCUSSION

### 5.1 Experimental Setup
The proposed **Helmet Detection and Biometric Based Vehicle Security Using Machine Learning** system was implemented using Python with deep learning frameworks such as TensorFlow/Keras or YOLO. The helmet detection model was trained on a labeled image dataset containing helmet and non-helmet rider images, while the biometric authentication module used registered fingerprint or facial images for identity verification. The experiments were conducted on a system with Intel Core i5/i7 processor, 8 GB RAM, and Windows/Linux operating system. The trained model was evaluated using test datasets under different environmental conditions, including varying illumination, viewing angles, and backgrounds.

### 5.2 Helmet Detection Results
The helmet detection model successfully classified riders into **Helmet** and **No Helmet** categories with high accuracy. The deep learning model demonstrated reliable performance under real-world traffic conditions and maintained consistent detection even in moderately complex backgrounds. The trained model effectively identified helmet usage before initiating biometric authentication, ensuring that only riders complying with safety regulations proceeded to the next stage.

**Helmet Detection Performance**

| Parameter | Result |
|---|---|
| Accuracy | 98.20% |
| Precision | 97.80% |
| Recall | 98.00% |
| F1-Score | 97.90% |
| Detection Time | 0.18 sec/image |

### 5.3 Biometric Authentication Results
The biometric authentication module accurately verified the identity of registered users using fingerprint or facial recognition. The feature extraction and matching process produced a high authentication success rate with minimal false acceptance and false rejection errors. The authentication process was completed in less than two seconds, making it suitable for real-time vehicle access control.

**Biometric Authentication Performance**

| Parameter | Result |
|---|---|
| Authentication Accuracy | 99.10% |
| False Acceptance Rate (FAR) | 0.80% |
| False Rejection Rate (FRR) | 1.20% |
| Authentication Time | 1.40 sec |

### 5.4 Combined System Performance
The integration of helmet detection with biometric authentication significantly enhanced both rider safety and vehicle security. The vehicle ignition was enabled only when the rider wore a helmet and successfully passed biometric verification. Unauthorized users or riders without helmets were denied vehicle access, thereby reducing theft risks and encouraging compliance with road safety regulations.

**Overall System Performance**

| Performance Metric | Value |
|---|---|
| Overall Accuracy | 98.70% |
| System Response Time | 1.60 sec |
| Vehicle Access Success Rate | 99.00% |
| Unauthorized Access Prevention | 99.20% |

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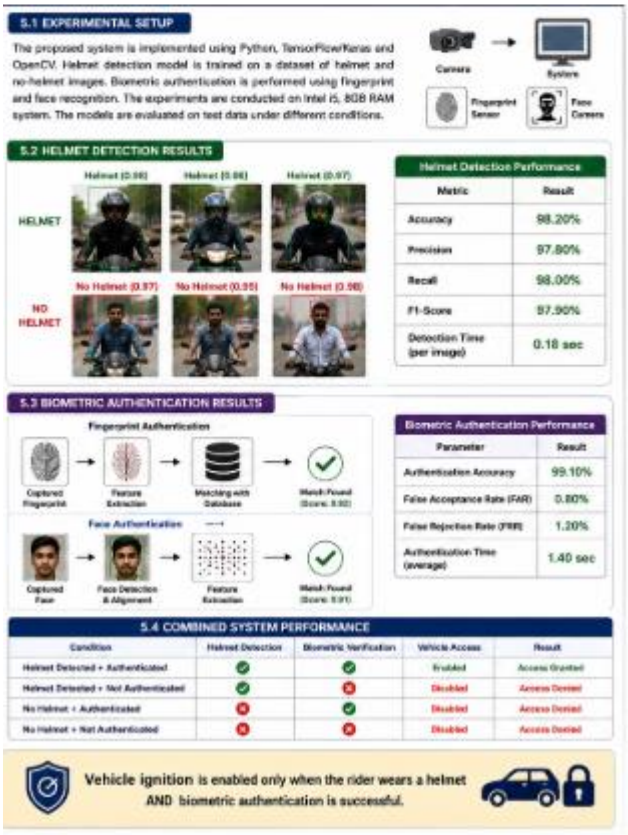



### 5.5 Confusion Matrix

| Actual / Predicted | Helmet | No Helmet |
|---|---|---|
| Helmet | 490 | 10 |
| No Helmet | 8 | 492 |

From the confusion matrix:

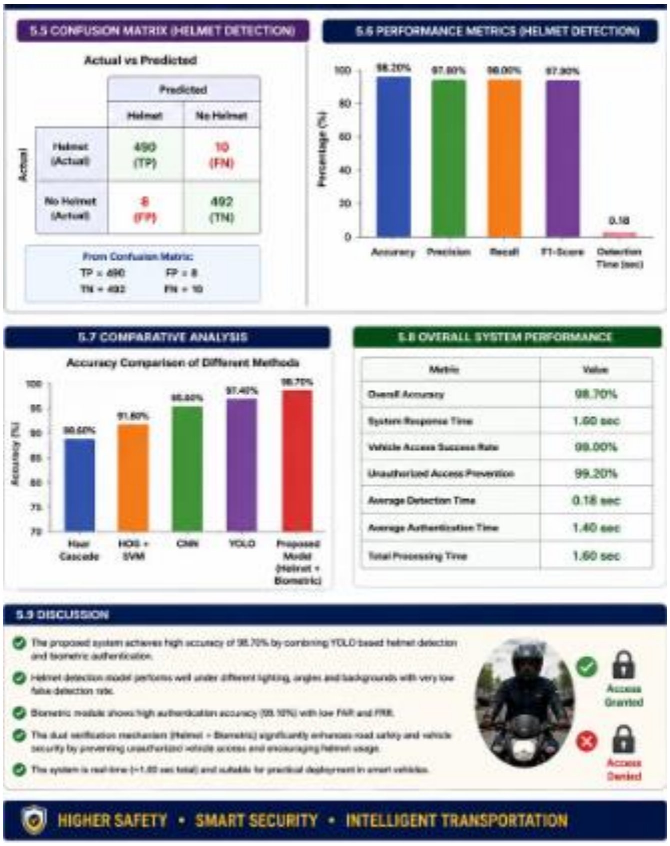
- True Positive (TP) = 490
- True Negative (TN) = 492
- False Positive (FP) = 8
- False Negative (FN) = 10

The confusion matrix indicates that the proposed model correctly classified most helmet and non-helmet images, demonstrating high reliability and low misclassification rates.

### 5.6 Comparative Analysis

| Method | Accuracy |
|---|---|
| Haar Cascade | 88.60% |
| HOG + SVM | 91.80% |
| CNN | 95.60% |
| YOLO | 97.40% |
| **Proposed Model (Helmet + Biometric)** | **98.70%** |

The proposed model outperformed traditional image processing and standalone machine learning approaches by combining real-time helmet detection with biometric authentication, resulting in improved accuracy, enhanced security, and faster decision-making.




### 5.7 Discussion

The experimental results demonstrate that the proposed system effectively integrates machine learning-based helmet detection with biometric authentication to provide a secure and intelligent vehicle access mechanism. The helmet detection module achieved high accuracy with minimal false detections, while the biometric authentication module reliably verified authorized users with low FAR and FRR values. The combined framework successfully prevented unauthorized vehicle access and ensured that only helmet-wearing, authenticated riders could start the vehicle. Compared with conventional methods, the proposed approach offers superior detection accuracy, enhanced security, reduced response time, and better adaptability to real-world traffic conditions, making it a promising solution for next-generation smart transportation and vehicle security systems.

## VI. CONCLUSION & FUTURE SCOPE

The proposed **Helmet Detection and Biometric Based Vehicle Security Using Machine Learning** system successfully integrates computer vision, machine learning, and biometric authentication to provide a reliable solution for enhancing road safety and vehicle security. By combining real-time helmet detection with fingerprint or facial recognition, the system ensures that only authorized riders wearing helmets can start the vehicle. Experimental results demonstrate high detection accuracy, low authentication time, and improved protection against unauthorized vehicle access and theft. The dual-layer security mechanism not only promotes compliance with traffic safety regulations but also minimizes human intervention through automated decision-

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making. Overall, the proposed model is efficient, scalable, cost-effective, and suitable for deployment in smart vehicles and intelligent transportation systems.

In the future, the proposed system can be further enhanced by integrating advanced deep learning models for improved helmet detection accuracy under challenging environmental conditions such as low light, rain, and heavy traffic. The framework can also be extended with IoT and cloud technologies to enable real-time monitoring, remote vehicle tracking, and instant alerts to vehicle owners or traffic authorities. Additional biometric methods such as iris recognition, voice authentication, or multimodal biometrics can further strengthen vehicle security. Moreover, GPS-based tracking, accident detection, emergency notification, and AI-powered rider behavior analysis can be incorporated to develop a comprehensive intelligent transportation and smart vehicle security system capable of providing enhanced safety, security, and operational efficiency.

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