

AI-DRIVEN HELMET DETECTION AND IGNITION CONTROL SYSTEM FOR ENHANCED TWO-WHEELER SAFETY

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Abstract: This paper presents an intelligent safety prototype powered by artificial intelligence, designed to explore the synergistic integration of computer vision and Internet of Things technologies in enhancing safety compliance for motorcyclists. The system acts as a proactive safety proof of concept, employing real-time monitoring to ensure that the vehicle's ignition is activated only when certain safety conditions such as wearing a helmet and rider sobriety are satisfied.

The proposed system functions through four main stages within a controlled prototype setting. Initially, it uses a camera module and the YOLOv8 algorithm for real-time object detection, specifically to confirm the presence of a helmet. Next, integrated IoT hardware, which includes IR and alcohol sensors, monitors simulated rider conditions and identifies potential impact events. These inputs are then processed by an ESP32 microprocessor, which compares the data to predetermined safety criteria. Finally, the system implements an automated ignition interlock mechanism, showcasing its capability to dynamically manage a power circuit based on the combined outcomes of the safety evaluations. By merging computer vision with embedded hardware in a laboratory environment, this project demonstrates the viability of an intelligent interlock system as a foundational strategy for improving road safety and rider accountability.

Index Terms - Artificial Intelligence, YOLOv8, Internet of Things (IoT), ESP32, Smart Helmet, Ignition Interlock System

I. INTRODUCTION

The rapid expansion of urban centers and subsequent reliance on localized transportation have significantly increased the number of two-wheeled vehicles on global roadways. Although motorcycles represent an affordable and versatile transportation solution, they account for a disproportionate number of traffic related fatalities. Head injuries remain the primary cause of severe and lethal outcomes among riders; however, statistical data confirm that the consistent use of certified helmets can reduce fatal injury risks by 42% and head injuries by 69%. Despite these critical figures and existing legal mandates, helmet non-compliance and riding under the influence of alcohol remain persistent challenges that manual enforcement and intermittent checkpoints fail to resolve effectively.

The AI-Driven Smart Safety and Ignition Interlock Prototype address these safety gaps by redefining the relationship between the rider's behavior and vehicle operation. Through the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies, the system transforms a standard safety helmet into an active enforcement tool. This ensures that the vehicle remains immobilized unless the rider adheres to verified safety protocols, shifting the paradigm from passive monitoring to proactive prevention. The proposed system introduces a multilayered approach to rider protection by synchronizing visual perception with physical hardware sensors. An AI-powered object detection model, YOLOv8, provides high-precision verification of helmet usage in real time. Simultaneously, integrated sensors within the prototype framework monitored alcohol consumption and ensured that the helmet was securely fastened. This fusion of the digital and physical domains creates a "Safe-Start" condition, where the vehicle's ignition circuit is activated only after all safety parameters are successfully validated.

In addition to basic compliance, the system functions as a comprehensive emergency response tool. By incorporating motion-sensing technology, the prototype can detect high impact events and falls and automatically trigger alert notifications to emergency contacts. This transition from linear manual surveillance to a holistic automated safety model significantly improves rider accountability and reduces response time during accidents. By modernizing safety enforcement through advanced AI and embedded systems, the proposed framework establishes a new standard for intelligent transportation systems (ITS).

The rest of this paper is organized as follows: Section II reviews related studies on vision-based helmet detection, monitoring rider sobriety, and existing IoT-based vehicle safety devices. Section III outlines the system architecture, offering a comprehensive overview of the integration between hardware and software, as well as the control logic based on the ESP32. Section IV details the proposed approach, emphasizing the use of the YOLOv8 detection algorithm and processing data from multiple sensors. Section V covers the hardware implementation and creation of the prototype in a controlled laboratory setting. Section VI evaluates the performance, results, and analysis of the safety start verification checks. Section VII discusses the current limitations and challenges faced in the development of the prototype. Section VIII suggests potential future research directions, such as scaling for real-world vehicle integration and cloud-based fleet monitoring. Section IX concludes the paper by summarizing the key findings and main contributions to the field of intelligent transportation systems, followed by the references.

II. RELATED WORK

The development of Intelligent Transportation Systems (ITS) has sparked a wide range of research aimed at improving rider safety through automated adherence to regulations. Current studies in this area are typically divided into two main technological paths: Computer Vision-Based Detection, which concentrates on the real-time visual surveillance of safety equipment, and IoT-Based Hardware Integration, which highlights the importance of physical sensors and vehicle level control systems. While initial safety strategies largely depended on passive monitoring, recent progress has moved towards integrating these two fields to establish more effective automated enforcement systems. By examining the unique advantages and latency challenges of these distinct categories, this section lays the groundwork for a hybrid model that combines AI-driven perception with embedded hardware intervention to ensure a comprehensive "Safe-Start" condition.

A. Design and Implementation of an AI and IoT Enabled Smart Safety Helmet for Real-Time Environmental and Health Monitoring

Ongoing advancements in personal protective equipment (PPE) have facilitated a paradigm shift from traditional, passive physical shielding toward sophisticated, active safety frameworks through the strategic integration of the Internet of Things (IoT) and Artificial Intelligence (AI). Modern methodological approaches prioritize the integration of high-performance sensory hardware within helmet architectures to facilitate the continuous, real-time monitoring of both environmental variables including temperature, humidity, and CO₂ concentrations and the physiological metrics of the user. To mitigate historical constraints regarding data processing and sensor precision, these systems utilize IoT connectivity to establish a networked ecosystem for remote administration and streamlined data transmission. This infrastructure is further refined by AI-driven analytics that move beyond passive data collection to enable predictive alerting and proactive hazard identification. By synthesizing these technologies, contemporary research establishes a high-fidelity safety model that replaces rudimentary smart features with advanced data analytics and remote oversight to minimize risks in high-stakes industrial environments.

B. Collision Prevention Technology in IoT Integrated Smart Bike Helmet

The methodological development of intelligent motorcycle safety headgear centers on the integrated deployment of microcontroller-based processing units alongside comprehensive sensor arrays and wireless communication protocols. At the architecture's core, primary controllers such as those based on ARM, Raspberry Pi, or Arduino platforms orchestrate data acquisition and oversee critical vehicle ignition logic. To ensure adherence to safety protocols, the methodology utilizes force sensing or mechanical limit switches within the helmet assembly to verify proper user engagement before enabling engine operation.

The system further incorporates specialized gas detection transducers to perform real-time breath analysis, providing an automated mechanism to immobilize the motorcycle should impairment thresholds be exceeded. For collision monitoring, the design utilizes multi-axis accelerometers and vibration sensors to identify high impact events or anomalous kinetic signatures. Upon detection of such an incident, integrated Global Positioning System (GPS) and Global System for Mobile Communications (GSM) modules facilitate the immediate transmission of geolocation data to designated emergency contacts. Additionally, the inclusion of ultrasonic proximity sensors and short-range wireless modules, such as Bluetooth or Radio Frequency (RF) interfaces, enables seamless data synchronization between the helmet and the motorcycle's internal control systems, thereby enhancing both situational awareness and reactive safety measures.

C. Smart Helmet for Alcohol Detection to Avoid Accidents in Bike Riders using IoT

To enhance motorized vehicle safety, the proposed methodology integrates a logic-based control architecture designed to govern ignition through the rigorous verification of rider compliance and sobriety. Central to this approach is a microcontroller managed circuit that processes real-time telemetry from integrated breath-alcohol transducers and proximity sensors. By establishing a digital interlock between the protective headgear and the vehicle's ignition control unit, the system enforces a safety critical protocol that prohibits engine activation absent the dual validation of correct helmet usage and breath-alcohol concentrations within established safety parameters. This proactive design framework aims to mitigate operational hazards associated with impairment and the omission of safety equipment. Ultimately, the efficacy of this strategy is contingent upon the precision of sensor calibration and the maintenance of reliable, high integrity communication between the helmet interface and the motorcycle's primary engine management system.

III. SYSTEM OVERVIEW

The proposed IoT-based intelligent safety and accident prevention system provides a real-time, autonomous monitoring solution for helmet compliance and rider safety. Utilizing a YOLOv8 based computer vision model, the system accurately detects helmet usage through continuous video frame analysis while simultaneously processing data from an array of safety sensors, including alcohol-level detectors and accelerometer-based fall detection modules. Upon detecting an anomaly such as the absence of a helmet or a confirmed accident the system's central logic unit initiates an immediate safety protocol by cutting the ignition via a relay-controlled DC motor and dispatching precise location data to emergency contacts. Communication is facilitated through an integrated Telegram Bot API, which delivers instantaneous alerts containing the rider's GPS coordinates. Additionally, the system features a manual safety override, allowing the rider to reset the ignition after resolving the issue, thereby ensuring a responsive and seamless interaction loop that prioritizes rider compliance and rapid emergency response.

A. System Architecture

The overall workflow of the system, as depicted in Fig. 1, is structured to ensure continuous monitoring and rapid response to unsafe conditions. The system consistently gathers telemetry data by measuring alcohol concentration through the MQ-3 sensor, capturing motion and orientation information using the MPU6050 module, and acquiring visual input for helmet detection through the YOLOv8 model. These inputs are processed in real time by the ESP32 control unit, where they are evaluated against predefined safety limits and logical conditions. If any abnormal situation is identified such as a fall event or violation of safety requirements the system immediately activates a protective mechanism that disables the vehicle’s ignition. Once this safety protocol is triggered, the system proceeds to obtain the current GPS location and sends an automated alert containing relevant details. The vehicle remains in a locked state until the rider manually intervenes by pressing the “Safe Button,” which acts as a reset trigger to clear the emergency condition and restore normal system operation.

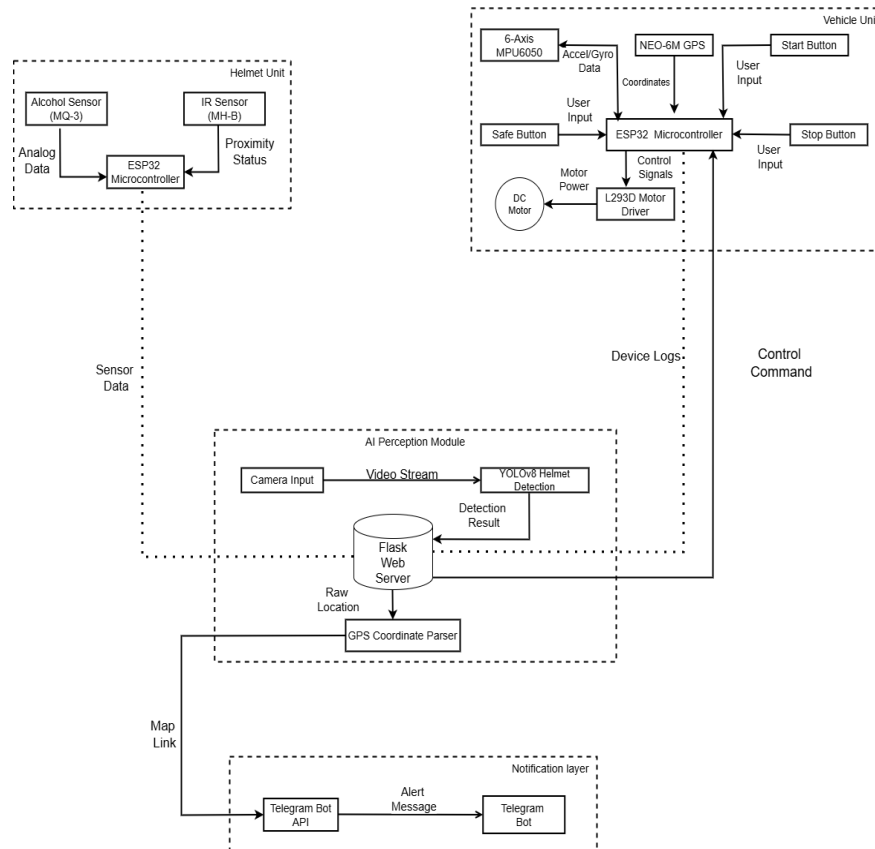


Figure 1. Architecture Diagram

B. System Hardware Design

The physical implementation of the safety system is based on a distributed hardware framework that separates sensing and control functions between the rider’s helmet and the vehicle’s ignition system. This design utilizes dual ESP32 microcontrollers as the primary processing units, chosen for their integrated Wi-Fi capabilities and robust handling of high-frequency sensor data. The helmet-side hardware is optimized for non-intrusive monitoring of rider compliance, while the vehicle-side infrastructure incorporates direct relay-based control to autonomously manage ignition safety protocols. By establishing a low latency communication link between these modules, the system ensures that critical safety interventions such as detecting helmet non-use or alcohol intoxication are executed with immediate physical effect. The following sections provide detailed circuit schematics and component specifications necessary to maintain this highly reliable safety environment. The hardware architecture is partitioned into two primary nodes to ensure localized and distributed processing. The Helmet-Side Node integrates sensors and an ESP32 to monitor rider compliance, featuring an IR-based proximity sensor for helmet detection. The Vehicle-Side Node is the main controller. It uses an ESP32 to connect to the MQ-3 alcohol sensor and the MPU6050 accelerometer to detect falls. This node further employs a relay module to manage the DC motor ignition, providing a hard-wired safety mechanism that operates independently of secondary network connectivity.

C. System Software Architecture

The software architecture follows a modular and loosely coupled design, implemented using a dual-layer approach that separates low-level firmware control from high-level processing logic. The lower layer is responsible for direct hardware interaction and safety enforcement, while the upper layer, built using a Python-based pipeline, handles computational tasks such as decision making and vision processing. The YOLOv8 model is utilized to process real-time video frames and accurately determine helmet usage with high confidence. This vision module runs in parallel with a telemetry processing unit that continuously acquires data from the MQ-3 alcohol sensor and MPU6050 accelerometer through high-frequency polling. An asynchronous, event-driven structure is used to ensure that sensor data acquisition, vision inference, and communication tasks operate concurrently without blocking each other, maintaining a lightweight and stateless system where critical parameters are stored only in temporary memory for quick transitions.

The communication and control layer is designed around API-based integration to handle external interactions and system responses. The Telegram Bot API is used as the primary interface for sending alerts, enabling asynchronous transmission of incident data. When a safety violation is detected, the system generates a structured JSON payload containing GPS coordinates and timestamp information, which is then securely transmitted. In addition, a priority-based interrupt mechanism is implemented to monitor the “Safe Button.” When triggered, this interrupt immediately overrides the ongoing execution flow and initiates a controlled reset of the ignition relay through software. By combining real-time video inference, continuous telemetry monitoring, asynchronous communication, and hardware-level interrupt handling, the system forms a reliable closed loop software framework suited for real-time mobile IoT safety applications.

D. Operational Workflow

The system operates through a structured closed-loop cycle aimed at ensuring continuous, high-frequency safety monitoring without relying on persistent data storage. The workflow begins with the data acquisition phase, where the system repeatedly collects hardware telemetry such as MQ-3 alcohol sensor readings, MPU6050 orientation and motion data, and real-time video frames used for YOLOv8-based helmet detection. All incoming data is temporarily held within the ESP32’s memory buffer. This acquisition is handled using a high-frequency, non-blocking polling mechanism, allowing the system to remain responsive and capable of handling multiple sensor inputs simultaneously without delay.

Following this, the safety policy evaluation phase functions as the decision-making layer of the system. In this stage, the continuously streamed sensor data is instantly validated against predefined safety thresholds and logical conditions. Any abnormal condition such as sudden tilt or fall detected by the accelerometer, alcohol levels exceeding permissible limits, or failure to detect helmet usage triggers an immediate state transition from normal “Monitoring” mode to an “Emergency” state, ensuring minimal latency in hazard detection.

In the emergency handling and recovery phase, the system initiates an automated response protocol designed for rapid intervention and user notification. Upon activation, the ESP32 fetches the current GPS coordinates, formats the data into a structured JSON payload, and transmits it via a secure asynchronous request to the Telegram Bot API, including precise location and time details. At the same time, the relay module is engaged to interrupt the vehicle’s ignition system, effectively preventing further operation. The system remains in this emergency state until a manual override is received through the “Safe Button.” This input acts as a hardware interrupt, resetting internal flags, clearing the emergency condition, and re-enabling the ignition relay, thereby restoring the system back to its normal monitoring cycle.

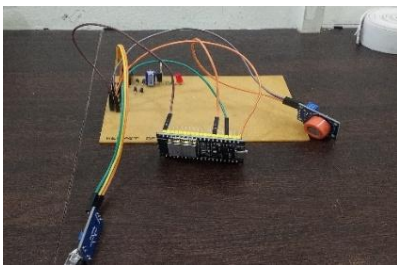


Figure 2: Helmet Unit

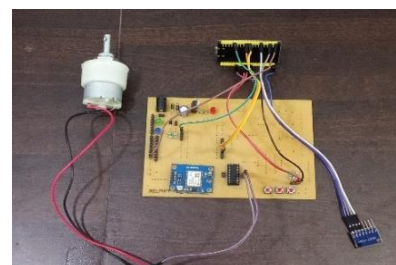


Figure 3: Vehicle Unit

IV. ALGORITHMS

The fundamental approach for the smart safety system employs a computer vision framework based on the YOLOv8 (You Only Look Once version 8) structure to enable real-time object identification. This deep learning model functions by handling individual input frames via a single forward-pass neural network, utilizing the Ultralytics framework to enhance inference efficiency. After capturing video data through the built-in imaging sensor, the system automatically conducts internal preprocessing such as image normalization and geometric resizing before sending the data through the model to produce object detection results.

The inference procedure produces an organized dataset that includes bounding box coordinates, class predictions, and related confidence scores. To guarantee detection precision, the system assesses these results against a specified confidence threshold while

utilizing internal Non-Maximum Suppression (NMS) to remove duplicate, overlapping detections and keep the best prediction. The bounding box information is subsequently aligned with the frame’s spatial dimensions to ensure accurate localization. Relying on a valid detection, the system classifies each frame as either “Helmet Detected” or “No Helmet,” visually verifying the status by drawing a bounding box around the recognized object. This detection pipeline functions in a constant, high-frequency cycle, offering the real-time decision-making ability essential for the larger automated safety system.

V. SYSTEM EVALUATION

The performance evaluation of the safety monitoring system was conducted using a confusion matrix to systematically assess the accuracy of helmet detection under different conditions. The matrix indicates that, out of the total instances belonging to the “Helmet” class, 92 were correctly classified, while 8 were incorrectly identified as “No Helmet.” In a similar manner, for the “No Helmet” category, 94 instances were accurately predicted, with only 6 misclassified as “Helmet.” The strong distribution of values along the diagonal elements clearly reflects a high rate of correct predictions, demonstrating that the YOLOv8-based detection model operates with a high degree of reliability during real-time evaluation.

A closer observation of these results shows that the occurrence of misclassification, including both false positives and false negatives, remains minimal. This is particularly significant in the context of a safety-critical application, where incorrect predictions could either lead to unnecessary system interventions or failure to detect unsafe conditions. The comparatively higher correct classification rate for the “No Helmet” class further emphasizes the system’s effectiveness in identifying safety violations, thereby supporting strict compliance enforcement.

Overall, the confusion matrix analysis confirms that the model maintains stable and consistent classification performance, with a well-balanced ability to distinguish between compliant and non-compliant states. This level of accuracy ensures that the system’s decision-making process remains dependable, enabling precise triggering of safety protocols when integrated with the underlying hardware control and alert mechanisms.

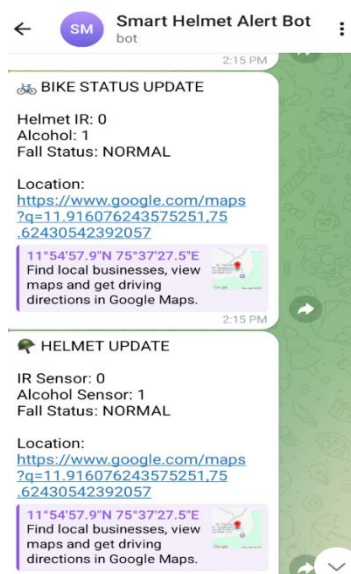


Figure 4: System Operational Status Notification

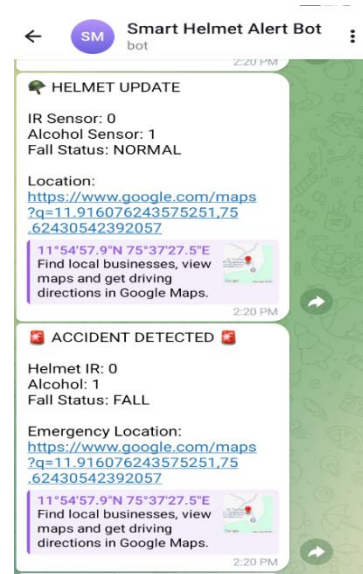
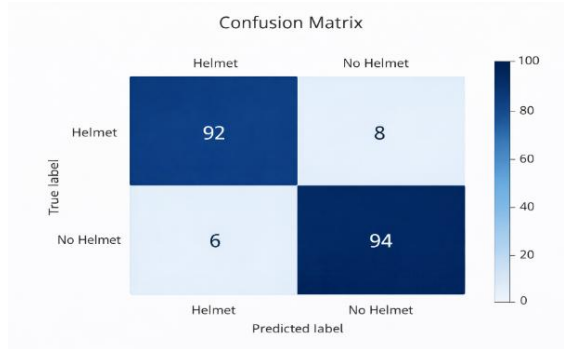


Figure 5: Automated Emergency Dispatch

VI. RESULT & DISCUSSION

The implemented safety monitoring system effectively allows for immediate verification of rider compliance and control of autonomous vehicle ignition. Employing a dual node setup with the ESP32 microcontroller and a YOLOv8-integrated vision pipeline, the system reliably detects safety critical metrics. The model analyzes high-resolution video streams to accurately classify states of helmet usage with elevated confidence levels, facilitating exact physical intervention in the vehicle's ignition system. When a safety violation is identified, the system immediately shifts into an emergency mode, implementing an effective notification process that utilizes the Telegram Bot API to convey timestamped incident details and accurate GPS locations to the rider’s emergency contacts. Experimental findings show reliable functioning in various settings, with specialized hardware controls overseeing ignition status.



The Start button serves as the main initiator, whereas the Stop button enables manual cessation of ignition. After an emergency like a collision or malfunction detection, the system implements a lockout to prevent operation. In this condition, the Safe button acts as the manual recovery interrupt, resetting the system and re-engaging the ignition relay after resolving hazards. While the system attains excellent operational accuracy, occasional delays can occur due to network variations or environmental barriers impacting sensor accuracy.

These results validate the feasibility of combining IoT-equipped hardware management with AI-powered vision to create a proactive safety atmosphere. Performance metrics, confirmed by a multi-class confusion matrix, illustrate the system's capability to effectively distinguish between normal functioning and significant safety failures. This design shows great promise for commercial motorcycle uses by incorporating real-time tracking, automated reporting, and ignition-related safety measures.

VII. LIMITATION

The proposed system has certain limitations, although it successfully combines vision, IoT telemetry, and hardware controls, encounters various limitations that affect its practical reliability. Environmental conditions like dim lighting, intense rainfall, or reflections can diminish video quality, resulting in lower confidence in helmet detection. Moreover, variations in camera stability due to road vibrations or sudden changes in exposure can activate incorrect emergency alerts. The system depends on reliable cellular connections for instant Telegram notifications; in locations with inadequate network infrastructure, sending essential GPS coordinates and incident information could be postponed.

A key architectural limitation is the lack of a consistent onboard database. The system is intentionally built to keep parameters in volatile memory, providing almost immediate state changes and low latency; however, this leads to the loss of past incident records when the device is turned off. This absence of persistence hinders extensive telemetry evaluations and thorough "black box" investigations following accidents. Additionally, the MQ-3 alcohol sensor might encounter environmental interference, necessitating future shielding at the hardware level. Upcoming efforts will concentrate on merging multi-modal sensor fusion to enhance detection precision, incorporating efficient non-volatile storage for incident recording, and optimizing the YOLOv8 model for improved efficacy in noisy environments.

VIII. CONCLUSION

The proposed AI-driven motorcycle safety and monitoring system powered by AI effectively showcases the ability to combine computer vision, IoT telemetry, and hardware ignition control to establish a proactive ecosystem for rider safety. The architecture transforms traditional methods of vehicle safety and accident prevention by allowing the system to independently check helmet compliance, identify dangerous rider conditions, and perform prompt ignition actions. By combining the ESP32 microcontroller with a YOLOv8-based inference engine, the system provides a responsive, context-sensitive interface that connects intelligent real-time monitoring with physical vehicle protection.

The system emphasizes the collaborative connection between AI's analytical skills and IoT's operational management abilities. AI enables precise recognition of safety critical objects and hazard assessment through telemetry, while the hardware component converts these alerts into actionable responses like ignition locking and instant incident reporting through the Telegram API. Collectively, these technologies convert conventional, passive motorcycle safety practices into a dynamic, automated safety system that considerably shortens the interval between an accident happening and emergency response, thus improving rider survival rates and response effectiveness.

A significant accomplishment of the system is its capacity to automate safety enforcement independently of continuous human oversight. This method enables the system to function as a dependable, always observant safety partner that alleviates the need for continuous self-regulation from the rider, guaranteeing that essential safety protocols are upheld even in stressful or emergency situations. Evaluation metrics, such as the multi-class confusion matrix, corroborate the system's substantial precision and effectiveness in differentiating between regular operations and safety critical failures, affirming its dependability as a fundamental safety component.

In summary, through the integration of real-time AI-driven processing and secure hardware ignition management, it delivers a reliable framework for improved road safety, emergency assistance, and proactive risk management. Upcoming advancements will emphasize migrating hardware to stronger computational platforms, establishing persistent onboard data logging, and enhancing bi-directional user communication, leading to more intelligent, interactive, and rider focused safety ecosystems. As this technology advances, these integrated solutions can fundamentally transform how riders engage with their vehicles, providing a safer and more secure riding experience in changing real-world conditions.

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