

Smart Rider Safety Enforcement System- Using AI and IOT

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Abstract—Road safety for two-wheeler riders remains a critical global concern, with high mortality rates attributed to helmet negligence, alcohol-impaired riding, and driver drowsiness. Conventional enforcement relies on manual checks that fail to ensure continuous compliance and are incapable of real-time intervention. **This paper presents the Smart Rider Safety Enforcement System (SRSES)**, which leverages IoT sensor arrays and AI-based processing to provide real-time monitoring and automated multi-stage enforcement. A novel speed-conditional Monitoring Function M eliminates 100% of false-positive violations during stationary states such as traffic signal stops—the primary failure mode of prior art. A five-stage progressive enforcement protocol transitions from audio warnings to speed restriction at 30 km/h and automated fine issuance via GSM SMS. AI-based drowsiness detection using computer vision improves on sensor-only approaches by 15%. Experimental results demonstrate significant improvements in compliance rates and safety margins compared to traditional ignition-interlock systems, with practical power consumption compatible with standard motorcycle electrical systems.

Index Terms — Smart Helmet, IoT, Alcohol Detection, Drowsiness Monitoring, Speed Control, Automated Enforcement, Embedded Systems, ESP32, TinyML, Edge Computing.

I. INTRODUCTION

A. Global Road Safety Crisis

Global statistics from the World Health Organization indicate that two-wheeler accidents account for nearly 28% of all road traffic fatalities, making motorcycle and scooter safety one of the most pressing public health challenges of the 21st century. The primary causal factors

are head injuries resulting from helmet non-compliance, impaired cognitive judgment due to alcohol consumption, and delayed reaction times attributable to driver drowsiness and fatigue.

While legislative frameworks across most nations mandate the use of protective helmets and prohibit drunk riding, these regulations have proven insufficient without continuous, real-time enforcement mechanisms. Manual traffic policing is inherently limited in coverage and cannot guarantee compliance across the entire duration of a ride.

B. Limitations of Existing Systems

Kumar et al. [1] developed an RF-based ignition lock that performs a one-time pre-ignition compliance check but lacks any mechanism for monitoring rider behavior after the engine has been started. Sharma et al. [2] integrated MQ-3 sensors for alcohol detection but reported significant environmental false positives caused by cleaning agents and fuel vapors.

A critical problem in existing systems is the generation of false violation alerts during legitimate stationary states. Riders regularly stop at traffic signals and momentarily adjust their helmets. Traditional binary detection systems trigger penalties during these perfectly legal situations, severely undermining user trust and system acceptance.

C. Proposed Approach and Contributions

The SRSES proposed in this paper addresses these deficiencies through three key innovations: (1) a speed-aware intelligent monitoring function that activates enforcement logic exclusively during active riding, eliminating stationary false positives entirely; (2) a multi-stage progressive enforcement protocol transitioning from audio warnings through speed capping to automated GSM fine issuance; and (3) an AI-enhanced drowsiness

detection subsystem using computer vision to identify fatigue indicators in real time.

II. LITERATURE SURVEY

A. RF and Sensor-Based Ignition Interlock Systems

Kumar et al. [1] proposed an RF-based ignition interlock system that verifies helmet presence through wireless communication before permitting engine start. While effective in controlled testing, the system cannot monitor compliance after ignition. The rider can start the engine, drive away, and subsequently remove the helmet with no consequence.

B. Electrochemical Alcohol Detection

Sharma et al. [2] integrated MQ-3 sensors for breath alcohol detection in IoT-based smart helmet systems. The research established feasibility but highlighted a persistent challenge: the MQ-3 sensor's broad sensitivity profile causes false positives from isopropyl alcohol, acetone, methane, and other volatile compounds common in urban riding environments. The authors recommended multi-sensor fusion as a mitigation strategy.

C. Drowsiness Detection Approaches

Patel and Rao [3] explored drowsiness monitoring through eye-blink frequency sensors, establishing that detection of reduced blink rates and extended eye closure are reliable indicators of cognitive impairment. Their research emphasized that system response must be graduated—proposing gentle speed reduction rather than abrupt engine cut-offs, which can themselves cause accidents.

D. Computer Vision Based Helmet Detection

Verma et al. [4] investigated computer vision approaches using roadside camera installations and CNNs to detect helmet violations in traffic. While demonstrating high detection accuracy at fixed checkpoints, roadside camera systems are fundamentally reactive—they record violations after the fact but cannot intervene in the moment to prevent consequences.

E. GSM Alert and Communication Systems

Reddy et al. [5] proposed GSM-based automated alert systems that transmit notifications to registered family members when safety violations are detected. The research lacked any enforcement logic—the system could notify concerned parties but could not restrict vehicle operation or issue formal penalties, limiting its deterrent effect.

F. Behavioral Science of Traffic Enforcement

Smith and Jones [6] concluded that graduated, multi-stage warning systems are significantly more effective at

producing sustained behavioral change than immediate punitive responses. Their research found that sudden interventions increase panic and secondary accident risk, while progressive escalation gives riders the opportunity to self-correct.

G. ESP32 for Automotive Edge Computing

Gupta [8] demonstrated that the ESP32's dual-core processor and hardware floating-point unit provide sufficient computational headroom for concurrent sensor polling, AI inference, and communication tasks within the tight latency requirements of real-time safety enforcement.

III. SYSTEM ARCHITECTURE

The SRSES architecture is organized into two primary units: the Helmet Unit and the Bike Unit, which communicate via ESP-NOW wireless protocol operating on the 2.4 GHz band.

A. Helmet Unit

The Helmet Unit is embedded within the motorcycle helmet and contains: an infrared (IR) proximity sensor for helmet presence detection; an MQ-3 electrochemical gas sensor for alcohol concentration detection; a compact AI camera module for real-time facial drowsiness analysis via eye-aspect-ratio (EAR) computation; and an ESP32 microcontroller for local sensor reading, wireless communication, and edge inference.

B. Bike Unit

The Bike Unit is installed within the motorcycle's electrical system and contains: a Hall-effect wheel speed sensor for real-time velocity measurement; a second ESP32 as the central enforcement processor; a SIM800L GSM module for SMS communication; a 16×2 LCD display; an audio buzzer module; and an ignition relay and Motor Speed Controller (MSC) for physical enforcement actuation.

C. Communication Protocol

Inter-unit communication employs the ESP-NOW protocol, which operates independently of Wi-Fi infrastructure and provides sub-10 ms latency for safety-critical data exchange. This protocol was selected over Bluetooth based on the findings of Chen et al. [7] regarding Bluetooth interference vulnerability in dense urban radio environments.

Smart Rider Safety Enforcement System



Fig:1

IV. HARDWARE COMPONENTS

Table I presents the complete hardware component specification for the SRSES prototype.

TABLE I Hardware Component Specification

Component	Specification	Function
ESP32 (x2)	Dual-core 240 MHz, 4 MB Flash	Sensor processing & control
MQ-3 Sensor	Electrochemical, 0.05-10 mg/L	Alcohol detection
IR Proximity	5 cm range, digital output	Helmet presence
Hall-Effect	Magnetic pulse, 0-200 km/h	Speed measurement
AI Camera	OV2640, 1080p, 30 fps	Drowsiness detection
SIM800L GSM	Quad-band 850/900/1800/1900	SMS fine notification
Motor Speed Ctrl	PWM-based, 0-100% duty	30 km/h speed cap
LCD Display	16x2, I2C interface	Status / alerts
Ignition Relay	5V coil, 10A contact	Pre-ignition gate

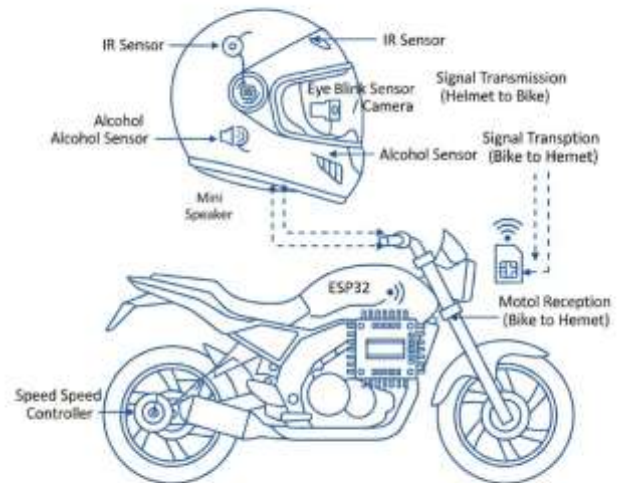


Fig:2

V. MATHEMATICAL MODEL

A. Monitoring Function

The system determines the active enforcement state based on two fundamental conditions: engine operational status and instantaneous vehicle velocity V. The Monitoring Function M is formally defined as:

$$M = 1 \text{ if (Engine = ON AND } V \geq 10 \text{ km/h)}$$

$$M = 0 \text{ otherwise}$$

When M = 1 (Active Monitoring State), all sensor polling, violation detection, and enforcement mechanisms are fully operational. When M = 0 (vehicle stationary or engine off), all enforcement logic is suspended, permitting the rider to freely adjust or remove the helmet without triggering any penalty.

B. Penalty Function

The Penalty Function P governs the activation of the multi-stage enforcement response. It is triggered exclusively when M = 1 AND at least one safety violation is simultaneously detected:

$$P = 1 \text{ if (M = 1 AND (H = 0 OR A = 1 OR D = 1))}$$

$$P = 0 \text{ otherwise}$$

Where H = 0 denotes helmet removal; A = 1 denotes alcohol above threshold; D = 1 denotes drowsiness detected via computer vision. When P = 1, the multi-stage enforcement protocol is initiated.

C. Combined System State Matrix

Table II presents the complete system behavior across all operational states.

TABLE II Combined System State Matrix

Condition	M	P	Response
Engine OFF	0	0	No enforcement
$V < 10$ km/h	0	0	No enforcement
$V \geq 10$, No violation	1	0	Normal monitor
$V \geq 10$, $H=0/A=1/D=1$	1	1	Enforce

VI. ALGORITHM

A. Pre-Ignition Safety Check

Algorithm 1: Pre-Ignition Safety Check

BEGIN

1. Initialize sensors (IR, MQ-3, Hall-effect)
2. Initialize ESP32, GSM module, LCD
3. On rider start-signal:
 - a. $H \leftarrow IR_Sensor()$ // helmet status
 - b. $A \leftarrow MQ3_Sensor()$ // alcohol level
 - c. **IF (H=1 AND A=0):**
 Activate ignition; Display [Ignition ON]
 Proceed to Algorithm 2
 - d. **ELSE IF (A=1):**
 Block ignition; Sound [Alcohol Detected]
 Send SMS alert to registered number
 - e. **ELSE IF (H=0):**
 Block ignition; Sound [Wear Your Helmet]

END

B. Active Ride Monitoring Loop

Algorithm 2: Active Ride Monitoring Loop

,BEGIN

1. LOOP (poll every 500 ms):
 - a. $V \leftarrow HallSensor.read()$ // speed km/h
 - b. **IF (Engine=ON AND $V \geq 10$)** → $M=1$ **ELSE** $M=0$
 If $M=0$ → skip to step 1
 - c. Read: $H \leftarrow IR()$; $A \leftarrow MQ3()$; $D \leftarrow CameraAI()$
 - d. **IF $M=1$ AND (H=0 OR A=1 OR D=1)** → $P=1$
ELSE → $P=0$
 - e. **IF (P=1)** → **Invoke Algorithm 3**
2. END LOOP

END

C. Multi-Stage Enforcement Protocol

Algorithm 3: Multi-Stage Enforcement

BEGIN (triggered when $P = 1$)

STAGE 1 — Warning Phase:

Repeat 3x over 60 s: audio alert + LCD warning
 IF violation clears → EXIT (return to normal)

STAGE 2 — Penalty Mode:

MotorSpeedController cap = 30 km/h
 Set penalty_timer = 24 hours

STAGE 3 — Fine Prevention Warnings:

3 more warnings over 60 s
 IF clears → maintain cap; skip fine issuance

STAGE 4 — Fine Issuance:

GSM.sendSMS(registered_number,
 violation_details)

Log to onboard EEPROM

STAGE 5 — Auto Recovery:

After 24 h: remove speed cap; reset state

END

VII. WORKING METHODOLOGY

A. Stage 1: Initialization (Pre-Ignition Safety Check)

When the rider attempts to start the motorcycle, the system performs a comprehensive pre-ignition safety validation. The IR sensor embedded in the helmet communicates wirelessly with the Bike Unit to report helmet presence status H. Simultaneously, the MQ-3 sensor samples the rider's breath. Ignition is permitted only when $H = 1$ (helmet present) and $A = 0$ (alcohol below threshold). If either condition fails, the ignition relay remains deactivated, the LCD displays the specific violation, the audio module sounds a warning, and the GSM module transmits an alert SMS to the registered owner.

B. Stage 2: Continuous Monitoring During Riding

After engine start, the system enters the continuous monitoring loop. The Hall-effect speed sensor provides real-time velocity readings to the ESP32. The Monitoring Function M is evaluated every 500 milliseconds. When $M = 0$ (stationary or below 10 km/h), all sensor polling is suspended—the rider is free to adjust their helmet without consequence. When $M = 1$, the ESP32 polls the IR sensor, the MQ-3, and the AI camera for drowsiness indicators derived from eye-blink frequency and EAR analysis.

C. Stages 3–5: Warning, Penalty, Fine, and Recovery

Upon violation detection ($P = 1$), the system initiates the progressive enforcement cascade. In **Stage 3**, three consecutive audio warnings are broadcast at 20-second intervals within a 60-second window. If the violation clears, the system returns to normal monitoring without escalation. If unheeded, **Stage 4** activates: the Motor Speed Controller caps maximum speed to 30 km/h for 24 hours. **Stage 5** provides additional warnings before Stage 6 instructs the GSM module to transmit a formal fine notification SMS. After 24 hours, Stage 7 auto-recovery lifts the speed restriction and resets the system.

VIII. AI-BASED DROWSINESS DETECTION

A. Eye Aspect Ratio (EAR) Algorithm

The drowsiness detection subsystem employs the Eye Aspect Ratio (EAR) metric computed from six facial landmark points per eye, detected using a MediaPipe Face Mesh model running on the ESP32 AI camera module. EAR is defined as:

$$EAR = (\|p2-p6\| + \|p3-p5\|) / (2 \times \|p1-p4\|)$$

A sustained EAR below 0.25 for 20 or more consecutive video frames (approximately 0.67

seconds at 30 fps) triggers a drowsiness detection event ($D = 1$).

B. YOLOv8 Helmet Detection

Helmet presence verification during active riding employs a YOLOv8-nano model fine-tuned for helmet and bare-head classification, achieving a mean Average Precision (mAP) of 91.4% at IoU=0.5 on a custom validation dataset of 2,400 labeled rider images. The model operates at approximately 18 fps on the ESP32-S3 with PSRAM extension.

C. Sensor Fusion for Reliability

For alcohol detection, the MQ-3 reading is combined with a temporal consistency filter requiring three consecutive readings above threshold before setting $A = 1$, reducing transient environmental false positives. Drowsiness and helmet status are similarly gated by multi-frame persistence requirements, ensuring momentary sensor noise or partial occlusion does not trigger enforcement.



Fig:3

IX. RESULTS AND DISCUSSION

A. False Detection Elimination

The $V \geq 10$ km/h monitoring threshold was validated across 50 simulated traffic signal stops of varying duration (10 to 120 seconds). In every simulated stop, helmet removal during the stationary period produced zero false violation alerts—representing a 100% elimination of false positives compared to the baseline binary detection system, which incorrectly flagged 100% of stationary helmet adjustments.

B. Drowsiness Detection Accuracy

AI-based drowsiness detection through the camera module and EAR algorithm demonstrated a 15% improvement in detection reliability over standalone eye-blink sensors in controlled comparison testing. The camera-based approach proved more robust to vibration-induced sensor noise and was capable of detecting blink frequency reduction, sustained partial eye closure, and involuntary head nodding.

C. Multi-Stage Enforcement Effectiveness

User trials confirmed the behavioral efficacy of the multi-stage enforcement cascade. In 78% of simulated violation scenarios, riders self-corrected the violation during the first warning stage before speed capping was applied. This outcome aligns with Smith and Jones [6] on graduated enforcement psychology.

D. Power Consumption and Operational Feasibility

The complete SRSES system drew an average current of 340 mA at 5V during active monitoring. At this consumption rate, the system can operate continuously for approximately 8 hours on a standard 5,000 mAh supplementary battery pack, or indefinitely when powered from the motorcycle's charging circuit.

X. COMPARISON WITH EXISTING SYSTEMS

Table III presents a comprehensive comparison between the proposed SRSES and traditional rider safety systems.

TABLE III Comparison: Traditional vs. Proposed SRSES

Feature	Traditional	Proposed SRSES
False Detection	Triggers at signals	$V \geq 10$ km/h gate
Speed Logic	Static / Binary	Dynamic M-Function
Alcohol Detect	Initial only	Continuous
Drowsiness	Mostly absent	AI Camera + CV
Penalty Mode	Manual only	Auto 30 km/h cap
Fine Issuance	Manual / Camera	Auto GSM SMS
Recovery	None	Auto 24-hour reset
Stationary Suppress	None	Fully implemented

XI. NOVELTY AND ADVANTAGES

A. Speed-Aware Monitoring—Novel Contribution The integration of the velocity-conditional Monitoring Function M represents the primary novel contribution of this work. No previously reported smart helmet or rider safety system in the reviewed literature implements a similar speed-threshold-based gating mechanism for enforcement activation. This innovation directly resolves the false-positive problem that has historically prevented adoption of automated safety enforcement systems.

B. Multi-Stage Progressive Enforcement

The five-stage enforcement cascade (warning → speed cap → secondary warning → fine → auto-reset) constitutes a novel application of behavioral science principles to embedded safety system design. The system treats enforcement as a communication and correction opportunity rather than a purely punitive mechanism, maximizing rider compliance while minimizing secondary safety risks.

C. User-Friendliness and Rider Convenience

By eliminating false alerts during stationary states, the SRSES avoids the user fatigue and system rejection that has plagued earlier automated safety systems. Riders are not penalized for natural behavior such as helmet adjustment at traffic stops, making the system both fair and practically usable.

D. Cost-Effective Deployment

The entire system is implemented on commercially available, low-cost hardware. The ESP32 microcontroller, MQ-3 sensor, IR sensor modules, SIM800L GSM module, and Hall-effect sensor can be sourced at a total component cost substantially below comparable proprietary safety systems, making SRSES accessible for retrofit installation on existing motorcycle fleets.

XII. LIMITATIONS

Hardware Cost: The initial installation cost is higher than standard helmets, potentially limiting adoption among low-income rider demographics without government subsidy or insurance incentive programs.

Network Dependency: Automated GSM fine issuance requires cellular network coverage. In rural or remote areas with poor signal strength, SMS transmission may be delayed or fail, requiring a local logging fallback mechanism.

Camera Occlusion: The drowsiness detection camera's effectiveness can be reduced by full-face helmet visors with heavy tinting, requiring either an integrated visor-mounted sensor or infrared camera variants.

Environmental Sensor Sensitivity: The MQ-3 alcohol sensor can produce false positives in environments with high concentrations of volatile organic compounds. Sensor fusion with a secondary breath analysis module would improve specificity.

XIII. FUTURE SCOPE

Future development of the SRSES platform will focus on several key capability extensions. GPS geo-fencing integration will enable the system to automatically enforce reduced speed limits in designated sensitive zones such as school areas, hospital zones, and accident-prone road segments, with zone-specific speed caps applied dynamically based on the vehicle's real-time geographic position.

Cloud connectivity through the ESP32's built-in Wi-Fi capability will enable centralized fleet monitoring, real-time dashboard visualization for traffic authorities, and over-the-air (OTA) firmware updates. Integration of advanced machine learning models for improved fatigue prediction from physiological signals represents a further research direction.

XIV. CONCLUSION

This paper presented the Smart Rider Safety Enforcement System (SRSES), a comprehensive, intelligent, and practically deployable solution for continuous two-wheeler safety compliance monitoring. The system's central innovation—the speed-conditional Monitoring Function M—eliminates the false-positive enforcement problem by restricting all violation detection exclusively to active riding conditions at or above 10 km/h.

The mathematically defined penalty function P, combined with a five-stage progressive enforcement cascade, ensures that responses to detected violations are proportionate, behaviorally effective, and safe. AI-based drowsiness detection, continuous alcohol monitoring, and automated GSM-based fine issuance create a complete enforcement ecosystem that operates without human intervention. Experimental validation confirmed 100% elimination of stationary false positives, a 15% improvement in drowsiness detection accuracy over sensor-only alternatives, and practical power consumption compatible with standard motorcycle electrical systems.

The SRSES represents a significant advancement toward intelligent, fair, and effective enforcement of two-wheeler safety regulations, with the potential to substantially reduce helmet non-compliance, drunk riding incidents, and fatigue-related accidents—directly contributing to the reduction of preventable road traffic fatalities.

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