Design of a Fully Local On-Vehicle AI System for Driver State Detection

This report presents a comprehensive design and research study for a fully local (edge-based) AI system capable of detecting driver intoxication, drowsiness, and sleep states using multimodal sensor fusion. The system is designed for a final-year engineering project with scalability toward production deployment in the Indian automotive context.

1. Problem Statement & Objectives

Road accidents caused by drunk and drowsy driving are a major public safety issue. Cloud-dependent solutions suffer from latency, privacy, and reliability concerns. This project aims to design a fully on-vehicle AI system that processes all data locally and classifies the driver into four states: Sober & Alert, Drunk, Sleepy/Drowsy, and Asleep.

2. System Overview

The system integrates vehicle telemetry (CAN/OBD-II), in-cabin vision, and inertial sensors. AI inference runs entirely on an embedded edge compute unit. Only alerts and logs are transmitted externally when required.

3. Driving Style Analysis (Vehicle Sensors)

Driving behavior is analyzed using signals accessed from the CAN bus or OBD-II interface.

- Steering wheel angle variance – detects overcorrection and erratic control
- Lane deviation – inferred via steering + yaw correlation
- Sudden braking and acceleration – intoxication indicator
- Speed oscillation – unstable throttle control
- Yaw rate, throttle position, brake pressure

4. Facial & Behavioral Analysis (In-Cabin Camera)

An in-cabin camera continuously monitors facial and head behavior.

- PERCLOS (percentage of eye closure)
- Eye blink rate and closure duration
- Head pose estimation (pitch, yaw, roll)
- Yawning detection using mouth aspect ratio
- Gaze tracking and fixation loss
- Facial micro-expressions associated with intoxication

5. AI / ML Model Design

Feature extraction is performed independently on sensor and video streams, followed by multimodal fusion.

- Tree-based models (Random Forest, Gradient Boosted Trees) for explainability
- Lightweight CNN for facial feature embedding

- CNN output fused into decision tree ensemble
- Confidence scoring and calibrated thresholds for safety

6. Edge Computing & Embedded Constraints

- Real-time inference <100 ms end-to-end latency
- Thermal envelope below 15W for prototype devices
- Model optimization: INT8 quantization, pruning
- Frame skipping and adaptive FPS at night

7. Hardware Components

A two-tier hardware strategy is adopted.

7A. Compute & AI Processing

- Prototype Tier: NVIDIA Jetson Nano / Orin Nano, Raspberry Pi + Coral TPU
- Production Tier: Qualcomm Snapdragon Auto, NXP i.MX 8, TI Jacinto
- RAM: 4–8 GB, Storage: 32–128 GB eMMC/SSD

7B. Vision Hardware

- IR + RGB camera, 720p–1080p, 30 FPS
- IR illumination for night driving
- Dashboard or A-pillar placement

7C. Vehicle Interface & Sensors

- OBD-II / CAN transceiver (MCP2515)
- IMU: 6-axis accelerometer + gyroscope
- Optional alcohol gas sensor for cabin air
- GPS module for alert localization

7D. Communication & Security

- LTE/5G modem with fallback buffering
- Secure Element / TPM for key storage
- Secure boot and firmware integrity checks

8. Decision & Alert Logic

A temporal sliding window aggregates predictions from all modalities. Alerts are triggered only when consensus confidence exceeds safety thresholds to reduce false positives.

9. Trusted Communication & Alerting

- Encrypted MQTT/HTTPS for alerts
- Alerts sent to police control room with GPS, timestamp
- Parallel alert to registered family contacts
- Offline buffering and retry on network restoration

10. System Architecture (Textual)

Sensors → Edge Compute (AI Inference) → Decision Engine → Secure Alert Module → External Authorities / Contacts

11. Ethics, Legal & Safety (India)

- Privacy-by-design, local-only inference
- Explicit user consent during vehicle registration
- Alignment with ISO 26262 functional safety principles
- AI output as decision support, not sole legal evidence

12. Validation & Testing

- Public datasets + controlled driving experiments
- Night, rain, highway stress tests
- Precision-recall trade-off analysis

13. Research Gaps & Future Enhancements

- Federated learning for privacy-preserving improvement
- Driver-specific personalization models
- Direct integration with national traffic enforcement systems