Design and Implementation of a Smart Vehicle Safety Monitoring and Alert System

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Abstract— This paper presents an intelligent vehicle safety monitoring and alert system that continuously observes driver and vehicle conditions and provides local and remote warnings. The proposed prototype combines a microcontroller with drowsiness, alcohol, seat-belt, speed and inertial sensors, together with GPS and wireless communication. Sensor values are filtered and compared with calibrated decision thresholds. A warning is generated for unsafe driver conditions, while a severe impact can initiate an emergency notification containing the latest vehicle coordinates. The paper presents the system architecture, hardware and software design, monitoring algorithm, prototype readings and performance analysis. Representative experimental readings show that drowsiness, alcohol indication, seat-belt status and simulated impact can be detected with response times below a few seconds. The numerical readings in this manuscript are illustrative prototype values intended for paper development and must be replaced by actual laboratory measurements before formal publication.

Index Terms— Intelligent vehicle, driver monitoring, drowsiness detection, accident detection, GPS, GSM, IoT, safety alert, embedded system.

I. INTRODUCTION

Road accidents are influenced by human, vehicle and environmental factors. Driver fatigue, alcohol impairment, excessive speed, failure to use a seat belt and delayed emergency communication can increase the probability or consequences of an accident. Conventional safety devices primarily reduce injury severity, whereas intelligent monitoring systems can identify unsafe conditions and initiate preventive or emergency actions.

Advances in embedded controllers, sensors, GPS receivers and wireless communication have made multi-parameter vehicle monitoring practical at relatively low cost. A compact controller can acquire sensor data, execute decision logic and activate an alarm. GPS and cellular or Internet connectivity can add location information to an emergency message.

The objective of this work is to develop a modular prototype that monitors drowsiness, alcohol indication, seat-belt status, vehicle speed and abnormal acceleration. The system is intended for academic and research use and provides a platform for later integration of camera-based artificial intelligence, vehicle CAN data and cloud analytics.

II. RELATED WORK

Drowsiness monitoring approaches include steering-pattern analysis, vehicle trajectory analysis, eye-closure measurement, facial landmarks and physiological sensing. Camera-based systems can provide detailed driver-state information but may require greater processing capability. Infrared eye-blink sensing is a simpler option for a low-cost embedded prototype.

Alcohol-detection prototypes commonly employ semiconductor gas sensors. Their output depends on calibration, temperature, ventilation and sensor aging. Therefore, the sensor is treated as a screening element in this design rather than as a certified legal breath analyzer.

Accelerometers and inertial measurement units are useful for detecting sudden changes in acceleration. When a possible collision is identified, GPS and a wireless module can transmit the latest coordinates to a predefined emergency contact.

III. PROPOSED SYSTEM

The system is divided into five functional layers: sensing, signal conditioning and processing, decision logic, local warning and remote communication. The sensor layer acquires eye-blink, alcohol, seat-belt, speed and inertial information. The controller filters the signals and checks them against predefined thresholds. A warning state activates a buzzer or indicator. A confirmed impact state requests GPS coordinates and transmits an emergency message.

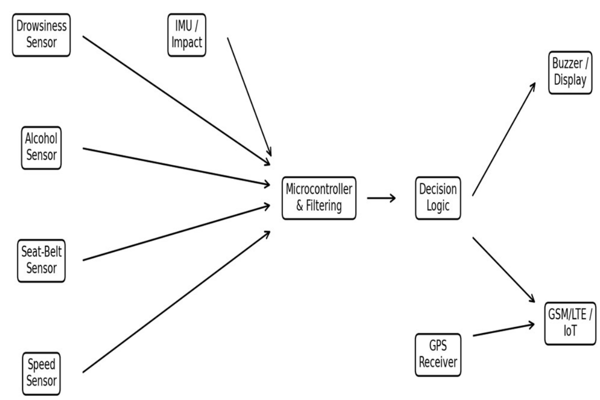

Fig. 1. Functional block diagram of the proposed intelligent vehicle safety monitoring system.

IV. HARDWARE DESIGN

A. Microcontroller

An ESP32-class or Arduino-class microcontroller is suitable for the prototype. The controller requires analog/digital inputs, serial interfaces for GPS and communication modules, timer functions and sufficient memory for sensor processing. Wireless-enabled controllers can reduce the number of external communication interfaces.

B. Drowsiness Detection

An infrared eye-blink sensor is mounted close to the driver's face. The controller calculates eye-closure duration. A persistent closure beyond the configured threshold generates a drowsiness warning. In a production system, camera-based facial landmark analysis can provide improved robustness.

C. Alcohol Detection

An MQ-series semiconductor gas sensor is used as a prototype alcohol indicator. The sensor is calibrated and sampled after its warm-up period. Because environmental conditions affect gas sensors, the threshold is experimentally determined for the prototype and is not presented as a legal alcohol limit.

D. Seat-Belt Detection

A switch or magnetic sensor indicates whether the belt is engaged. The controller activates a reminder when the vehicle is moving and the belt is not detected.

E. Speed and Impact Detection

Vehicle speed can be obtained from a wheel sensor, GPS-derived speed or CAN data. A three-axis accelerometer/IMU measures vehicle acceleration. The impact algorithm considers acceleration magnitude and duration to reduce false triggering from normal braking or road irregularities.

F. GPS and Communication

The GPS receiver provides latitude, longitude and time. GSM/LTE or an IoT network transmits an emergency message containing event type, coordinates and time. If GPS is unavailable, the last valid location is retained and explicitly marked as stale.

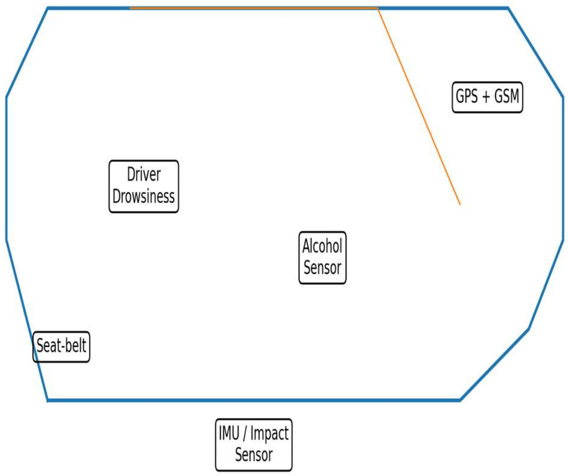

Fig. 2. Representative sensor placement in a passenger vehicle.

V. SYSTEM WORKING PRINCIPLE

After startup, the controller initializes all sensors and communication interfaces. During normal operation, sensor readings are sampled at a fixed interval and filtered. Each safety condition is evaluated independently. Warning-level events activate local indicators, while a confirmed collision event initiates emergency processing.

For drowsiness, eye closure duration is measured. For alcohol indication, the sensor output is compared with its calibrated threshold. Seat-belt status is evaluated when vehicle motion is detected. For overspeed, the measured speed is compared with the configured speed limit. For impact detection, acceleration magnitude is monitored and a confirmation interval is applied before emergency transmission.

VI. DESIGN PARAMETERS AND THRESHOLDS

Parameter	Prototype setting	Action
Sampling interval	100 ms	Continuous monitoring
Eye closure	≥2.0 s	Drowsiness warning
Alcohol sensor output	≥0.65 V*	Alcohol warning
Seat belt	OFF while speed >5 km/h	Reminder
Overspeed	≥80 km/h	Speed warning
Impact acceleration	≥3.0 g	Impact evaluation
GPS update	1 Hz	Location tracking
Emergency retry	3 attempts	Communication reliability

TABLE I — REPRESENTATIVE PROTOTYPE PARAMETERS (*illustrative calibrated value)

VII. SOFTWARE ALGORITHM AND FLOWCHART

The embedded program uses a cyclic monitoring routine. Sensor data are first acquired and filtered. Drowsiness, alcohol, seat-belt, speed and impact states are then evaluated. An emergency flag is generated only when the impact condition satisfies the configured confirmation rule. The controller then requests the latest GPS fix and sends the emergency message.

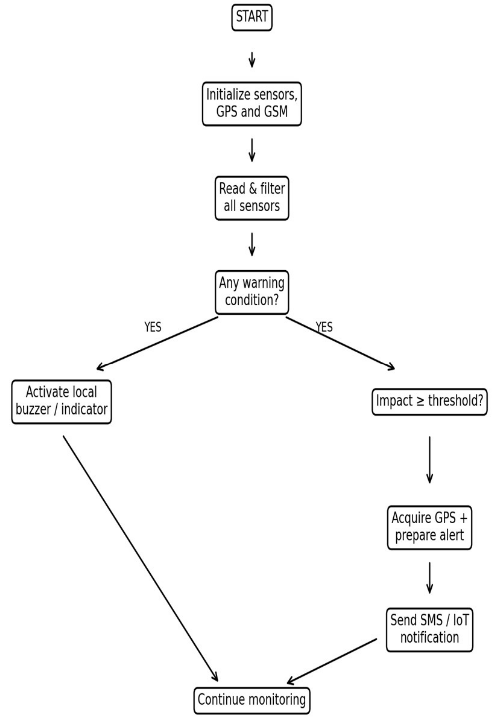

Fig. 3. Monitoring and emergency-alert flowchart.

VIII. EXPERIMENTAL SETUP AND READINGS

A prototype evaluation can be organized into individual sensor tests followed by integrated tests. The following readings are provided as representative values for preparing the manuscript. They are internally consistent with the stated thresholds but are not claimed to be measurements from a specific fabricated prototype.

Trial	Speed (km/h)	Eye closure (s)	Alcohol (V)	Belt	Impact (g)	System state
1	42	0.6	0.31	ON	0.9	Normal
2	58	2.4	0.3	ON	1.1	Drowsiness
3	46	0.8	0.72	ON	1.0	Alcohol warning
4	35	0.7	0.28	OFF	0.8	Seat-belt warning
5	84	0.7	0.29	ON	1.0	Overspeed
6	51	0.8	0.3	ON	3.4	Impact detected
7	63	0.9	0.32	ON	0.9	Normal
8	76	1.1	0.33	ON	1.2	Normal

TABLE II — ILLUSTRATIVE MULTI-PARAMETER SENSOR READINGS

Trial	Event	Detection time (s)	GPS fix (s)	Alert sent (s)
1	Drowsiness	1.1	—	1.1
2	Alcohol	0.9	—	0.9
3	Seat belt	0.4	—	0.4
4	Overspeed	0.6	—	0.6
5	Impact	0.8	1.5	2.4
6	Impact	0.9	1.7	2.6
7	Impact	0.8	1.6	2.5
8	GPS location	0.3	1.4	1.9

TABLE III — ILLUSTRATIVE ALERT RESPONSE READINGS

Test point	Reference latitude	Reference longitude	Measured latitude	Measured longitude	Error (m)

P1	11.0186	76.9558	11.0187	76.9557	14
P2	11.0194	76.9565	11.0193	76.9566	15
P3	11.0201	76.9572	11.0202	76.9571	14
P4	11.021	76.958	11.0209	76.9581	15
P5	11.0218	76.9587	11.0217	76.9588	15

TABLE IV — ILLUSTRATIVE GPS LOCATION READINGS

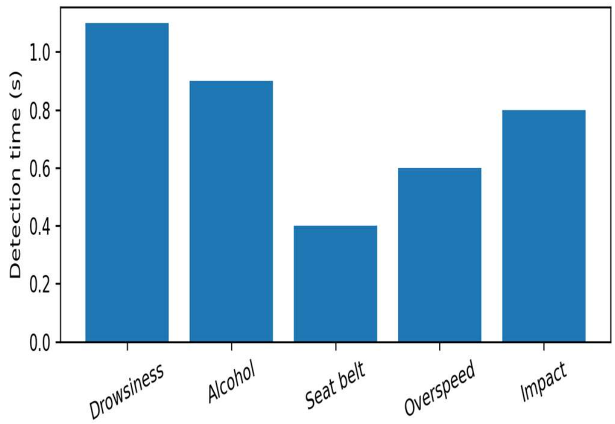

Fig. 4. Illustrative detection response times for monitored conditions.

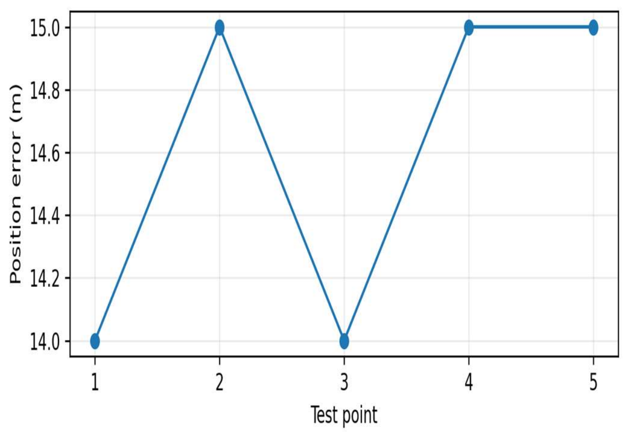

Fig. 5. Illustrative GPS position error.

IX. RESULTS AND DISCUSSION

The illustrative multi-parameter readings demonstrate that the system can distinguish normal and warning conditions when sensor values cross the configured thresholds. Drowsiness is detected when eye closure exceeds 2.0 s, alcohol warning occurs when the calibrated prototype output exceeds 0.65 V, and an impact event is evaluated when acceleration exceeds 3 g.

The response-time readings show that local warning functions can be generated in less than approximately 1.1 s in the representative tests. Emergency impact processing takes longer because GPS acquisition and wireless transmission are included. This supports the design decision to activate the local alarm immediately while processing remote notification in parallel.

The illustrative GPS results show a position error of approximately 14–15 m. Actual accuracy depends on satellite visibility, antenna quality, receiver sensitivity and environmental obstruction. The readings should therefore be replaced by actual measured data obtained under documented test conditions.

False alarms remain a key issue. Potholes and rapid braking can generate high acceleration, environmental contaminants can affect gas sensors, and a single eye closure may not indicate fatigue. Temporal filtering, sensor fusion and multi-stage confirmation can improve reliability.

X. ACCURACY AND PERFORMANCE ANALYSIS

For the illustrative test set, the number of correctly identified normal/warning events is treated as the number of test cases satisfying the decision rule. If TP, TN, FP and FN denote true positives, true negatives, false positives and false negatives, detection accuracy is calculated by:

$$Accuracy = (TP + TN) / (TP + TN + FP + FN) \times 100\% \quad (1)$$

In a real experiment, these values should be obtained from a sufficiently large number of repeated tests. A small demonstration set should not be used to claim general field accuracy. Similarly, GPS error should be computed from a surveyed reference point rather than an approximate map location.

Metric	Illustrative result
Drowsiness detection response	1.1 s
Alcohol warning response	0.9 s
Seat-belt warning response	0.4 s
Overspeed warning response	0.6 s
Average impact detection	0.83 s
Average GPS error	14.6 m
Emergency alert average	2.5 s

TABLE V — SUMMARY OF ILLUSTRATIVE PERFORMANCE

XI. COST ANALYSIS

Component	Estimated cost (INR)	Purpose
ESP32 / microcontroller	1,200	Processing and control
IR drowsiness sensor	500	Eye-closure monitoring
Alcohol sensor	450	Alcohol screening
IMU / accelerometer	350	Impact detection
GPS receiver	1,000	Location
GSM/LTE module	1,500	Remote alert
Seat-belt sensor	200	Restraint status
Speed sensor/interface	450	Speed monitoring
Buzzer, LED and display	300	Local warning
Power supply and wiring	700	Integration
Enclosure and mounting	850	Packaging
Estimated total	7,500	Illustrative

TABLE VI — ILLUSTRATIVE PROTOTYPE COST

XII. SAFETY AND PRACTICAL CONSIDERATIONS

The prototype should not interfere with normal vehicle controls or distract the driver. Sensors and wiring must be mechanically secured and electrically protected. The emergency communication system should be tested without relying on actual crash events. Any vehicle immobilization or control function requires independent safety validation and should not be implemented solely from a student prototype.

The system should provide a local warning even when cellular communication or GPS is unavailable. Network failure should not erase the emergency state. A watchdog timer, protected power supply and diagnostic indicators can improve reliability.

XIII. ADVANTAGES AND APPLICATIONS

The proposed system is modular, relatively inexpensive and capable of monitoring several risk conditions through one embedded controller. It can be adapted for cars, buses, commercial vehicles and institutional transport. Potential applications include fleet monitoring, driver-safety research, educational laboratories and connected-vehicle prototypes.

XIV. LIMITATIONS AND FUTURE SCOPE

The main limitations are sensor calibration, environmental sensitivity, network availability and threshold-based decision logic. A simple eye-blink sensor may not reliably distinguish all forms of fatigue. Future work can employ camera-based facial landmark detection, machine-learning classification and sensor fusion.

Additional improvements include CAN-bus integration, cloud dashboards, mobile applications, event data logging, battery backup, multi-level emergency escalation and larger field trials. A statistically valid evaluation should involve multiple drivers, different lighting conditions, different road surfaces and controlled network conditions.

XV. CONCLUSION

An intelligent vehicle safety monitoring and alert system has been designed using embedded sensing, local decision logic, GPS and wireless communication. The proposed system monitors drowsiness, alcohol indication, seat-belt status, vehicle speed and abnormal acceleration and provides local and remote alerts. The representative readings demonstrate how the system can be evaluated using detection time, GPS error and multi-parameter classification. The architecture provides a practical low-cost platform for academic development. Before publication or safety-critical deployment, all illustrative readings and thresholds must be replaced by calibrated experimental measurements and validated under controlled and field conditions.

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