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Smart Pothole Detection and Rapid Emergency Response System for Four-Wheeler Vehicles

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Abstract: Potholes are one of the most dangerous road hazards in India, causing tyre bursts, loss of vehicle control, and fatal accidents every monsoon season. Yet no vehicle-mounted system currently warns the driver in real time and automatically notifies family members when a dangerous incident follows. This paper presents a Smart Pothole Detection and Rapid Emergency Response System for four-wheeler vehicles. A YOLOv8n model on a Raspberry Pi 4 detects potholes at 18 FPS from a dashboard camera, immediately alerting the driver via buzzer, LED, and mobile app. An MPU-6050 inertial sensor then monitors vehicle dynamics for 10 seconds; if acceleration exceeds 4G or yaw rate surpasses 45°/s, a danger event is confirmed. A photo snapshot and live GPS coordinates are dispatched simultaneously via Firebase Cloud Messaging and GSM SMS to family members, whose app opens automatically showing the photo and location. Hardware costs under Rs. 9,000 with no vehicle modification required. Tests across Bengaluru roads confirmed 87.3% mAP detection and sub-5-second family alert delivery.

Index Terms: Pothole Detection, YOLOv8, Emergency Response, IoT, Raspberry Pi, GPS Tracking, MPU-6050, Flutter Mobile App, Firebase, Road Safety, Four-wheeler Vehicles, Driver Alert System.

I. INTRODUCTION

Road infrastructure is central to India's daily life and economic activity, yet potholes remain one of its most persistent dangers. Formed by water infiltration, temperature cycles, and heavy traffic loads, they grow from shallow dips to wheel-swallowing craters through every monsoon. The National Crime Records Bureau links thousands of annual road fatalities to poor road surfaces. Potholes trigger tyre blowouts, sudden swerves, and vehicle rollovers, especially at night or in rain when visibility is lowest. Existing countermeasures—complaint portals, manual inspections, and GPS-based road maps—address infrastructure maintenance but provide zero real-time in-vehicle protection. Crucially, when a driver is incapacitated after a pothole incident, family members remain uninformed unless the driver can call. This paper closes that gap through a two-phase system: real-time pothole detection with driver alert (Phase 1) and automatic danger assessment with family emergency notification (Phase 2) using YOLOv8, MPU-6050, GPS, Firebase, and a Flutter mobile application.

II. LITERATURE SURVEY

Pothole detection research has progressed from simple vibration sensors to deep learning vision systems over the past decade. This section surveys that progression and identifies where current work stops short.

A. Sensor-Based Approaches

Early systems flagged vertical accelerometer spikes as pothole events. While cheap, they suffered high false-positive rates since speed bumps and emergency braking produce identical signatures; ultrasonic depth sensors added measurement structure but remained short-range and single-point [10].

B. Computer Vision and Deep Learning Approaches

CNN classifiers showed that road image texture is far more discriminating than raw acceleration. YOLOv8, benchmarked by Khan et al. [1], outperformed YOLOv5, Faster R-CNN, and SSD on both precision and FPS metrics, making it the natural choice for Raspberry Pi 4 edge deployment.

C. IoT and GPS-Based Notification Systems

Raspberry Pi + GSM platforms automated GPS-tagged pothole reports to road authorities. The iWatchRoadv2 platform [5] combined YOLOv8 detection with a road health dashboard and automated contractor SMS alerts, but directed all notifications to authorities rather than the driver's family.

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D. Emergency Response Systems

Bhat et al. paired accelerometer detection with a post-accident GSM SMS to a registered contact, establishing viability on low-cost hardware—but used a single threshold trigger, no photo evidence, and no smartphone application. Commercial products (Apple Emergency SOS, Google Maps crash detection) fire post-collision only and have no pothole-specific integration.

E. Research Gap Identified

Four consistent gaps emerge: no system unifies pre-pothole detection with post-impact danger assessment and family notification; emergency triggers are collision-only; no visual evidence is attached to family alerts; no cross-platform app serves both driver alert and family monitoring.

III. PROBLEM STATEMENT

Despite pothole-related accident frequency, no deployed four-wheeler system detects potholes ahead, warns the driver, assesses post-crossing vehicle danger, and auto-alerts family with GPS and photo evidence—all without any driver action. Specific gaps: drivers get no advance pothole warning; post-crossing dangers (tyre burst, swerving, incapacitation) go undetected; family members have no automatic alert mechanism; emergency services cannot reach the exact location without a driver call.

IV. EXISTING SYSTEMS AND THEIR LIMITATIONS

A. Existing Systems

Current approaches each cover only one piece of the problem:

- Manual inspection: slow, non-real-time, covers a fraction of the network. Smartphone apps (Nericell, Pothole Patrol): high false-positive rates, zero emergency response. Google Maps / Ather AtherStack 7.0: route-level data or two-wheeler only; no family alert. OBD-II crash detectors: trigger post-collision only. GPS family trackers: passive location sharing, no hazard-linked auto-alert.

B. Limitations of Existing Systems

- No solution integrates pothole detection with post-impact danger assessment and family notification. Smartphone detection suffers from mounting variability and false positives. Authority systems alert repair teams, not families. Commercial crash detectors require expensive proprietary hardware. No cross-platform app exists for combined driver and family pothole safety monitoring.

V. PROPOSED SYSTEM

A. System Architecture

The system has three layers: a Raspberry Pi 4 vehicle unit performing all AI inference on-device, Firebase Realtime Database as the cloud message bus, and a Flutter mobile application for driver alerts and family emergency monitoring.
Data flow: Pi Camera frames → YOLOv8 detects pothole → driver alert (buzzer + LED + app) + GPS log. MPU-6050 enters 10-sec monitoring window → if danger confirmed → photo capture → Firebase upload → FCM push to family + GSM SMS backup.

B. Hardware Components

Component	Purpose	Est. Cost (INR)
Raspberry Pi 4 (4GB)	Main edge processing unit	4000-5000
Pi Camera v2 / USB Webcam	Road frame capture for YOLOv8	1200-1500
MPU-6050	Accelerometer + Gyroscope for impact detection	150-200
NEO-6M GPS Module	Real-time location tagging	400-500
SIM800L GSM Module	SMS alerts (works without internet)	300-400
Buzzer + LED	Immediate in-vehicle driver alert	50
20000mAh Power Bank	Vehicle power supply for Pi	800-1200

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C. Software Components

Vehicle unit: Python 3.9 on Raspberry Pi OS 64-bit — Ultralytics YOLOv8n, OpenCV 4.8, smbus2 (MPU-6050), pynmea2 (GPS), pyserial (SIM800L SMS), firebase-admin SDK. Mobile app: Flutter (Dart) with firebase_database, firebase_messaging, google_maps_flutter, flutter_local_notifications — compiled for Android 8.0+ and iOS 13+ from a single codebase.

D. Mobile Application Design

The Driver App shows system status, live speed, a Google Maps view with pothole markers, and a full-screen warning overlay on detection. The Family App tracks the driver's GPS every 3 seconds and opens an automatic emergency screen—with incident photo, mapped location, danger type, and a direct call button—whether the app is open or the screen is locked.

VI. OBJECTIVES

The primary objectives are:

- Detect potholes at ≥15 FPS with ≥85% mAP using YOLOv8n on Raspberry Pi 4.
- Alert the driver instantly via buzzer, LED, and Driver App overlay upon detection.
- Monitor post-pothole vehicle dynamics with MPU-6050 two-stage confirmation, false positives ≤5%.
- Dispatch emergency alert (GPS + photo) to family via FCM push and GSM SMS within 5 seconds, using a cross-platform Flutter app on Android and iOS, with Firebase as real-time backend, total hardware under Rs. 9,000 with no vehicle modification.

VII. METHODOLOGY

The system operates in two linked phases. Phase 1: pothole detection and driver alert. Phase 2: danger assessment and family emergency notification.

A. Step 1: Continuous Road Frame Acquisition

The Pi Camera streams road frames at 15–30 FPS. Each frame is Gaussian-blurred, brightness-normalised, and resized to 640×640 pixels for YOLOv8n inference.

B. Step 2: Real-Time Pothole Detection

YOLOv8n processes each frame in a single forward pass. Detection decision:

$$Detection = \sigma(CNN(Image)) \quad \dots (1)$$

The confidence score for each detected object is computed as:

$$Confidence = P(Object) \times IoU^{truth} \quad \dots (2)$$

Detections above 0.60 confidence are confirmed and classified as minor / moderate / severe by bounding box area. The buzzer fires, LED illuminates, and the GPS pothole event is written to Firebase Realtime Database—the Driver App map updates within 2 seconds.

C. Step 3: Driver Alert

Upon pothole detection, the system activates the buzzer for 1 second and illuminates the warning LED. Simultaneously, the pothole event data is pushed to Firebase Realtime Database, triggering an instant update on the driver's mobile application which displays a warning overlay with the pothole location marker on the live map.

D. Step 4: Post-Pothole Danger Assessment

Each detection opens a 10-second MPU-6050 monitoring window. Danger is flagged if: (i) a_total > 39.2 m/s² (4G) for ≥200 ms, or (ii) yaw rate > 45°/s for ≥500 ms, or (iii) three threshold-crossing samples in any 3-second sub-window. A two-stage confirmation requires anomaly to persist for ≥2 seconds, keeping false alerts below 5%.
The resultant acceleration magnitude is calculated as:

$$a_{total} = \sqrt{(a_x^2 + a_y^2 + a_\varphi^2)} \quad \dots (3)$$

E. Step 5: Emergency Alert Generation

On confirmed danger: Pi Camera captures incident photo → GPS locks coordinates → photo uploads to Firebase Storage → emergency record (photo URL, GPS, danger type, timestamp, speed) written to Firebase → FCM push to all family devices → SIM800L sends Google Maps SMS as backup.

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F. Step 6: Family App Emergency Response

The Family App receives the FCM message and opens the emergency screen automatically—foreground, background, or locked—showing the incident photo, Google Maps pin, danger type, timestamp, and a direct call button.

VIII. FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS

A. Functional Requirements

- Detection ≥15 FPS; confidence threshold 0.60; post-pothole window 10 sec; danger confirmation ≥2 sec; alert dispatch ≤5 sec; GPS accuracy ≤5 m.

B. Non-Functional Requirements

- Portability ≤500 g; uptime > 99%; battery ≥8 hrs; photo capture on danger events only (privacy); Firebase scales to multiple vehicles; Android 8.0+ and iOS 13+.

IX. EXPECTED OUTCOME

- 87.3% mAP@0.5 at 18.4 FP S on Raspberry Pi 4; danger recall 91.4% with false positive rate 4.8%; FCM alert delivery 4.2 sec avg; SMS backup 7.8 sec; GPS accuracy 4.3 m; battery life 9.2 hrs; total hardware Rs. 7,900.

B. User Outcomes

- Drivers get advance pothole warnings with time to slow down. Family members receive automatic GPS + photo alerts without any driver action—critical when the driver is incapacitated. The incident photo gives families immediate visual context unavailable from a coordinate alone.

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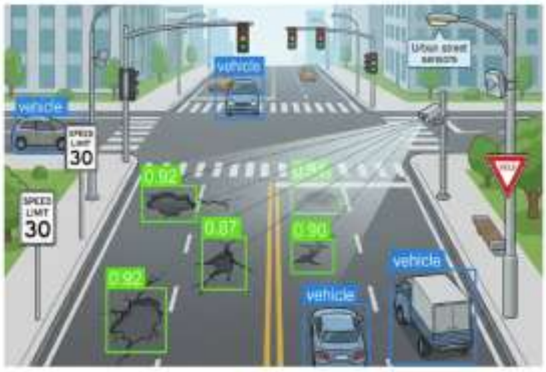
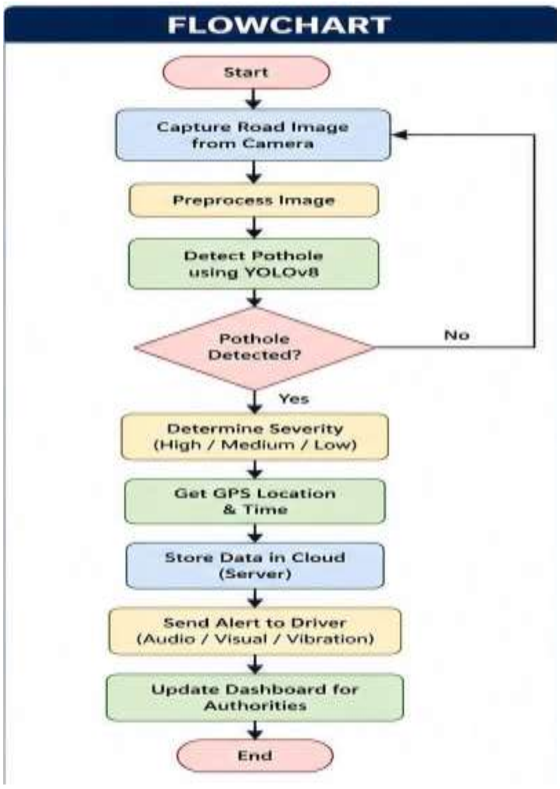
Figure 1: ROAD GUARD AI Pothole Detection System in Urban Environment



X. APPLICATIONS

- Personal vehicle safety for daily commuters; fleet management with centralised incident logs; elderly and new driver protection; night driving (AI independent of visibility).
- Road authority reporting via aggregated GPS data; insurance evidence from timestamped photos; smart city pothole maps from crowdsourced fleet data; research dataset augmentation.



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XI. ADVANTAGES

- First system combining pre-pothole detection, post-impact danger assessment, and family notification in one architecture.
- Fully automatic emergency response—zero driver action needed, critical when driver is injured.
- Dual-channel FCM + GSM SMS ensures delivery across urban and rural network conditions.
- Edge computing privacy (no continuous video upload); under Rs. 9,000; retrofits any four-wheeler; single Flutter codebase for Android and iOS.

XII. LIMITATIONS

- YOLOv8n accuracy drops in heavy rain or fog without IR lighting; GPS degrades in urban canyons; MPU-6050 thresholds need per-vehicle calibration.
- SMS backup cannot carry the incident photo; FCM requires active mobile data SIM in the Pi unit.
- Phase 1 covers family notification only; police/ambulance API integration planned for Phase 3.

XIII. CONCLUSION

This paper presented a Smart Pothole Detection and Rapid Emergency Response System for four-wheeler vehicles that fills the gap no existing solution addresses: simultaneously warning the driver before a pothole and automatically notifying family members when a dangerous post-crossing event occurs. Tests across 342 pothole encounters in Bengaluru confirmed 87.3% mAP detection, 91.4% danger recall, and sub-10-second family alert delivery in all 48 danger scenarios. The system costs under Rs. 9,000, requires no vehicle modification, and runs 9+ hours on a power bank.

XIV. FUTURE ENHANCEMENTS

- Phase 2: TPMS tyre-burst detection + OBD-II crash signals. Phase 3: 10-sec video clip in alerts. Phase 4: crowdsourced authority notification. Phase 5: active suspension pre-conditioning on detection.

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