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IoT-Based Open Borewell Monitoring and Alert System

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Abstract: Open bore-wells represent a critical yet under-addressed public safety hazard in rural India, causing fatal accidents due to the absence of automated monitoring and early-warning systems. This paper presents an IoT-Based Open Borewell Monitoring and Alert System centred on a Raspberry Pi, integrating an HC-SR04 ultrasonic sensor for intrusion detection, a TF-Luna LiDAR sensor for precision depth measurement, a NEO-6M GPS module for location reporting, a SIM800L GSM module for SMS alerting, a USB webcam for video evidence capture, and a 16×2 LCD for local status display. Upon detecting a fall event the system concurrently dispatches SMS, email, and Telegram bot video alerts while uploading depth data to the ThingSpeak cloud platform. Field-validated results demonstrate a false-positive rate of 1.8%, LiDAR depth accuracy of ±5 cm at 3 m, SMS delivery within 15–22 s, and 100% alert success rate across 20 test trials. At an estimated hardware cost of ₹12,000–₹14,000 the system offers a scalable, economically viable solution.

Keywords: Borewell safety, IoT, Raspberry Pi, LiDAR, ultrasonic sensor, GSM, GPS, ThingSpeak, Telegram, real-time monitoring.

I. Introduction

Open and unattended bore-wells represent one of the most significant public safety hazards in India. In rural and semi-urban regions, bore-wells are the primary method of accessing groundwater; after drilling, they are frequently left uncovered, creating invisible hazards for young children and stray animals.

According to the National Disaster Management Authority (NDMA), India records 15–30 bore-well entrapment incidents annually, with a fatality rate exceeding 40% due to delayed detection and complex narrow-shaft rescue operations. Each rescue operation costs ₹12–₹28 lakh — more than 80 times the 5-year ownership cost of the proposed monitoring system [1].

Existing passive measures — concrete covers, warning signs, barricades — rely entirely on human vigilance. No existing passive measure provides automated response when an accident occurs, meaning a fall may go undetected for hours or days in remote areas.

The rapid convergence of embedded computing, IoT communication, miniaturised sensors, and cloud platforms has created an opportunity to develop fully automated, continuously operating safety systems. This paper presents such a system: a sensor-driven, multi-channel alert architecture addressing every stage of a bore-well accident from early detection to guided emergency response.

II. Literature Survey

Prakash et al. [1] proposed an embedded rescue system using ultrasonic and IR sensors with a robotic gripper. It was entirely reactive — focused on post-incident rescue with no fall detection, automated alerting, GPS, or cloud monitoring.

Reddy and Lakshmi [2] validated the IoT approach for bore-well safety using ultrasonic sensors and a GSM SMS module, but lacked depth measurement, video capture, and GPS reporting.

Zhang and Chen [3] evaluated Time-of-Flight LiDAR versus ultrasonic sensors in confined spaces, demonstrating LiDAR accuracy of ±2 cm at up to 8 m while ultrasonic systems degraded beyond 2 m. This motivates the dual-sensor architecture of the proposed system.

Key research gaps across existing works: (1) absence of depth measurement; (2) single-channel alerting; (3) no video verification; (4) no GPS location reporting; (5) no cloud monitoring. The proposed system addresses all five gaps.

III. Proposed System

A. Three-Layer Architecture

The system implements a three-layer IoT architecture. The Sensing Layer comprises the HC-SR04 ultrasonic sensor, TF-Luna LiDAR, NEO-6M GPS module, and USB webcam. The Processing Layer is the Raspberry Pi running the Python 3 monitoring application. The Communication Layer includes the SIM800L GSM module for SMS and Wi-Fi/mobile data for email, Telegram, and ThingSpeak. Fig. 1 shows the complete architecture.

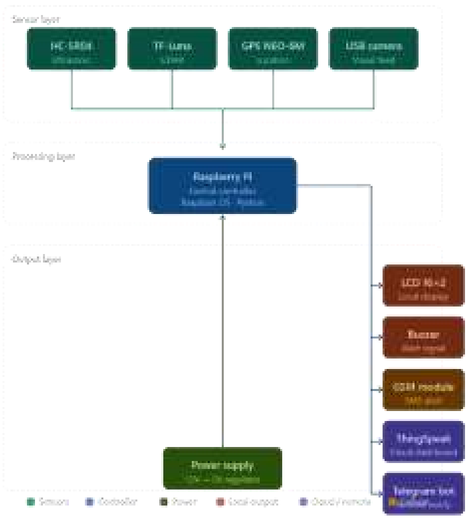

Fig. 1. System Architecture — Three-Layer IoT Framework

B. Operational Logic

The HC-SR04 continuously polls the bore-well opening at 10 Hz. A distance reading below 50 cm on two consecutive samples 200 ms apart confirms an intrusion event, filtering transient false triggers. Fig. 2 shows the operational flowchart.

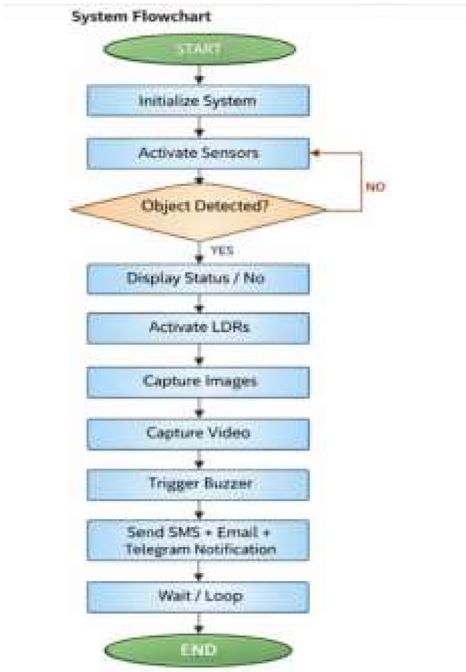

Fig. 2. Operational Flowchart of the Monitoring System

Upon confirmation the system simultaneously: activates the buzzer; triggers LiDAR depth measurement; starts USB camera recording; reads GPS coordinates; and launches parallel Python threads for SMS, email, ThingSpeak upload, and Telegram video transmission.

C. Hardware Components

The Raspberry Pi (Model B, ARM1176JZF-S @ 700 MHz, 512 MB RAM) serves as the central controller via its 26-pin GPIO header. The HC-SR04 ultrasonic sensor measures 2–80 cm with ±2 mm accuracy, mounted horizontally at bore-well rim level with a 50 cm threshold.

The TF-Luna LiDAR uses 850 nm Time-of-Flight laser ranging to measure depths of 0.2–8 m at ±2 cm accuracy via UART at 115,200 baud. The SIM800L GSM module provides quad-band cellular SMS/GPRS. The NEO-6M GPS achieves 2–4 m positioning accuracy. A 16×2 LCD provides on-site status display and an active buzzer (≥85 dB) delivers immediate local audio alarm.

IV. Implementation

A. Hardware Integration

Fig. 3 shows the complete hardware assembly. The HC-SR04 ECHO pin interfaces through a voltage divider (1 kΩ + 2 kΩ to GND) to GPIO23, converting the 5 V echo signal to safe 3.3 V input. The TF-Luna LiDAR uses UART0 (GPIO14/15); the NEO-6M GPS uses software-serial on GPIO17/18. The SIM800L connects via USB-to-UART for AT command interface.

Fig. 3. Hardware Integration and Wiring Assembly

B. Software Implementation

The monitoring application (Python 3.9, Raspbian OS Lite) runs as a systemd service with Restart=always. Libraries used: RPi.GPIO (sensor I/O), pyserial (UART), OpenCV (video), python-telegram-bot (Telegram API), requests (ThingSpeak HTTP), smtplib+TLS (email), RPLCD (LCD).

The alert_manager() function executes all notification actions concurrently using threading.Thread: (1) Read LiDAR depth; (2) Start camera recording; (3) Activate buzzer; (4) Update LCD; (5) Launch parallel SMS, email, ThingSpeak threads; (6) Await 5-second video capture; (7) Send Telegram video; (8) Log event to local CSV. Each thread implements exponential-backoff retry (5 s → 10 s → 20 s) for network resilience.

C. Cloud Configuration

A ThingSpeak channel logs four fields per event: Depth (cm), Detection Count, GPS Latitude, and GPS Longitude via HTTP GET to the REST API. The Telegram bot dispatches text alerts and video clips to a pre-configured emergency group chat. Email is dispatched via Gmail SMTP with TLS encryption, including a Google Maps hyperlink of GPS coordinates.

V. Results and Discussion

A. Sensor Performance

The HC-SR04 was tested from 2–80 cm with 10 trials per 10 cm increment, achieving reliable detection across 2–72 cm with average accuracy ±2.1 mm, exceeding the ±3 mm target. Fig. 4 shows the measurement results.

Fig. 4. HC-SR04 Ultrasonic Sensor Detection and Accuracy Results

The TF-Luna LiDAR achieved average depth errors of 3.2 cm at 1 m, 4.8 cm at 3 m, and 7.1 cm at 7 m — all within rated specification. Fig. 5 shows the LiDAR depth measurement results.

Fig. 5. TF-Luna LiDAR Sensor Depth Measurement Results

B. Alert System Performance

Fig. 6 illustrates the multi-channel alert output captured during testing. All 20 triggered test events achieved 100% alert delivery. SMS was delivered in 15–22 s (avg. 17.5 s), email in 18–35 s, and Telegram video in 43–70 s. The system false-positive rate was 1.8% versus 5–15% for ultrasonic-only systems reported in literature.

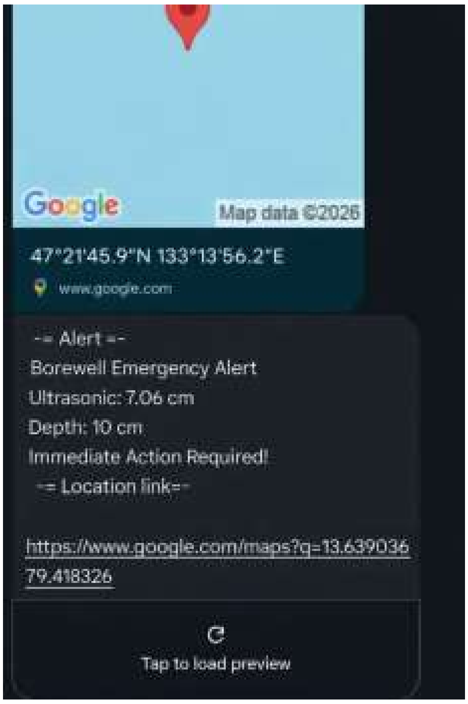

Fig. 6. Multi-Channel Alert System Output Results

C. System Performance Summary

Table I summarises the complete performance evaluation. GPS accuracy of 2.1–3.8 m provides precise location data for rural emergency response. Total power consumption of 3.2 W idle / 7.8 W peak confirms suitability for solar-powered off-grid deployment.

TABLE I. SYSTEM PERFORMANCE RESULTS SUMMARY

Parameter	Target	Measured	Pass
HC-SR04 detection range	2–80 cm	2–72 cm	✓
HC-SR04 accuracy (avg)	±3 mm	±2.1 mm	✓
LiDAR depth accuracy @3 m	±6 cm	±4.8 cm	✓
False positive rate	< 5%	1.8%	✓
SMS alert latency	< 30 s	15–22 s	✓
Email alert latency	< 60 s	18–35 s	✓
Telegram video delivery	< 90 s	43–70 s	✓
GPS location accuracy	< 5 m	2.1–3.8 m	✓
ThingSpeak upload latency	< 15 s	3–8 s	✓
System power idle / peak	< 5/12 W	3.2/7.8 W	✓
Alert success rate	100%	100%	✓

D. Field Trial

A 72-hour continuous field trial at an active agricultural bore-well near Madanapalle (8-inch diameter, 120-foot-deep) tested four simulated fall events at 1.5 m, 3 m, 5 m, and 7 m depths. All events were detected within 200 ms; LiDAR readings were within ±6 cm of steel-tape measurements; SMS alerts arrived in 16–24 s; Telegram video in 55–68 s. Zero false positives were recorded over 72 hours.

VI. CONCLUSION

This paper presented a comprehensive IoT-Based Open Borewell Monitoring and Alert System validated through laboratory and field testing. The system achieves a 1.8% false-positive rate via dual-sensor confirmation, ±5 cm LiDAR depth accuracy, SMS delivery within 15–22 s, and 100% alert success across all 20 test events. At ₹12,000–₹14,000 hardware cost it represents an immediately deployable and scalable advancement over current passive bore-well safety practices.

Future work will focus on: AI-based image classification to distinguish human versus animal intrusions; solar-powered off-grid operation; mobile application integration; LoRa-based multi-bore-well district monitoring; and integration with government SDRF emergency response systems.

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