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"ACCIDENT NOTIFICATION AND RESPONSE SYSTEM: A REVIEW OF DETECTION, COMMUNICATION AND EMERGENCY-RESPONSE TECHNOLOGIES"

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ABSTRACT

Road-traffic crashes remain a major public-health and transportation-safety problem, and the interval between a collision and the arrival of professional assistance can strongly influence injury outcomes. Accident notification and response systems attempt to shorten this interval by automatically detecting a probable crash, estimating its severity, determining the vehicle location, communicating an alert, and supporting dispatch of emergency services. This review examines the evolution and present architecture of such systems, with emphasis on sensor-based detection, Global Navigation Satellite System positioning, cellular and Internet-of-Things communication, smartphone-assisted solutions, cloud platforms, machine-learning methods, and integrated emergency-response workflows. The literature shows a progression from simple vibration-switch and GSM alert prototypes toward multi-sensor fusion, ESP32/Arduino-based embedded systems, cloud-connected dashboards, visual situation reporting, dual-channel communication, and standardized services such as the European 112 eCall. Accelerometers, gyroscopes, vibration sensors, airbag or vehicle-bus signals, GPS/GNSS receivers, GSM/LTE modules, and mobile applications are the most frequently reported components. However, reliable real-world deployment remains constrained by false alarms, network availability, sensor calibration, location uncertainty, power loss after impact, cybersecurity, privacy, interoperability, and limited validation using real crashes. The review argues that future systems should be designed as complete response chains rather than isolated accident detectors. Promising directions include context-aware sensor fusion, edge artificial intelligence, vehicle-to-everything communication, 5G/next-generation connectivity, automatic severity estimation, redundant communication, standardized data exchange with emergency control rooms, and privacy-preserving cloud analytics. A robust accident notification and response system can therefore serve as an important component of intelligent transportation systems by reducing notification delay and improving the quality of information available to rescuers.

Keywords: Accident detection; emergency notification; emergency response; Internet of Things; GPS; GSM

I. INTRODUCTION

Road safety continues to demand sustained technological and policy attention. The World Health Organization reported approximately 1.19 million road-traffic deaths annually, while tens of millions of people experience non-fatal injuries. Road-traffic injury is also a leading cause of death among people aged 5–29 years [1], [2]. Although crash prevention is the first priority, post-crash care is equally important because serious trauma may require rapid location, triage, rescue and transport. Conventional accident reporting depends heavily on a conscious occupant, a witness, or a passer-by making a telephone call. This dependency can create a critical information gap when occupants are unconscious, the crash occurs at night or in an isolated area, or witnesses cannot accurately describe the location.

An Accident Notification and Response System (ANRS) addresses this gap by linking crash sensing with communication and emergency action. In its simplest form, a sensor detects a sudden impact, a microcontroller verifies a threshold, a GPS receiver obtains coordinates, and a GSM module sends an SMS to predefined contacts. More advanced systems fuse acceleration, angular motion, vibration, speed, airbag status and vehicle-bus data; upload information to a cloud platform; estimate crash severity; provide an occupant-cancellation window for false alarms; and transmit information directly to emergency dispatch centers [3]–[7]. Thus, the core objective is not merely to recognize an accident, but to convert an uncertain physical event into a reliable, timely and actionable emergency message.

The importance of this integrated view is illustrated by the European 112 eCall service. In a serious crash, eCall automatically contacts the 112 emergency number and sends a minimum set of data that includes the vehicle location, time and direction of travel. The European Commission has reported that eCall can substantially shorten emergency-response time, particularly in rural areas [8]. The concept demonstrates the value of interoperability between the vehicle, telecommunications network and public-safety answering point. Research prototypes worldwide seek similar functionality using low-cost embedded electronics and IoT platforms.

This paper reviews the principal technologies, architectures, research trends and implementation challenges associated with accident notification and response. It emphasizes the complete chain from detection to rescue, compares major design approaches, and identifies future research requirements for dependable real-world systems.

II. EVOLUTION OF ACCIDENT NOTIFICATION SYSTEMS

Early automatic accident-alert concepts were dominated by threshold-based embedded systems. A vibration switch or accelerometer was connected to a microcontroller, and a large measured impact triggered an alarm. GPS and GSM subsequently became common because they provided two essential capabilities: geographic localization and long-range communication. Systems based on Arduino, MEMS accelerometers, GPS and GSM demonstrated that a low-cost device could automatically notify family members or emergency services without requiring the injured occupant to initiate a call [3], [9].

The emergence of smartphones expanded the sensing platform. Modern phones contain accelerometers, gyroscopes, magnetometers, GNSS, cellular connectivity and processing power. Research therefore explored smartphone-based crash classification and multimodal alerting, sometimes combining onboard diagnostics (OBD-II) data with mobile-phone sensors [10], [11]. Smartphone solutions reduce dedicated hardware cost, but performance depends on device mounting, operating-system restrictions, battery condition, sensor sampling rate and whether the phone remains functional after a severe crash.

IoT-based architectures represent the next stage. Shaik and co-authors demonstrated a smart-car concept in which accelerometer and GPS information could be sent to the cloud and used to notify subscribed emergency recipients [4]. Later systems added cloud databases, web dashboards, MQTT communication, mobile applications and dual GSM/GPRS channels. Aslam and co-authors proposed an automatic system that combines acceleration, angular movement and vibration and can create visual information for rescue operators, addressing the problem that a basic SMS conveys location but little situational context [5]. Recent ESP32-based prototypes have also used redundant alert channels such as GSM-SMS and Internet messaging to improve the probability that at least one alert reaches its destination [6].

The current research direction is therefore toward connected safety ecosystems. The accident detector is becoming one node in a wider intelligent transportation system involving vehicles, smartphones, cloud servers, emergency centers, hospitals, police, family contacts and potentially vehicle-to-everything infrastructure. This shift increases capability, but also makes reliability, data standards and cybersecurity more important.

III. SYSTEM ARCHITECTURE AND WORKING PRINCIPLE

A generalized ANRS can be divided into six functional layers: sensing, decision, localization, communication, emergency coordination and data management. The sensing layer acquires physical evidence of abnormal vehicle behavior. The decision layer determines whether the event is sufficiently consistent with a crash. The localization layer

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identifies where the event occurred. The communication layer transmits the alert. The emergency-coordination layer converts the notification into dispatch or contact actions. Finally, the data-management layer records event information for monitoring, analysis and system improvement.

During normal operation, inertial and vehicle signals are sampled continuously. A sudden acceleration peak, rapid change in velocity, unusual roll or pitch angle, strong vibration, airbag deployment, or a combination of these variables activates a candidate-event state. Instead of sending an alert immediately, many designs use a confirmation procedure. A short countdown may allow an uninjured driver to cancel the notification, while sensor fusion can verify that multiple crash indicators are present. Once confirmed, the controller retrieves GNSS coordinates and constructs an emergency packet containing vehicle identification, time, latitude, longitude, detected severity and possibly occupant or medical information.

The alert may be transmitted by SMS, voice call, packet data, a mobile application, MQTT, cloud notification or V2X communication. Redundant communication is desirable because an accident can damage an antenna, interrupt one network, or occur where mobile data are unavailable. A remote server can display the accident on a map, notify emergency contacts, identify the nearest response unit, and preserve the event record. Standardized systems such as eCall additionally establish a voice connection and send a defined minimum dataset to a public-safety answering point [8].

Table 1. Functional elements of a typical accident notification and response system

Layer	Typical technologies	Primary function	Key concern
Sensing	Accelerometer, gyroscope, vibration, airbag/OBD	Identify abnormal crash dynamics	False positives and calibration
Decision	Threshold logic, sensor fusion, ML	Confirm event and estimate severity	Generalization across vehicles
Localization	GPS/GNSS, cellular positioning	Determine accident coordinates	Urban canyon/tunnel availability
Communication	GSM/SMS, LTE/5G, GPRS, Internet, V2X	Deliver emergency data	Coverage and post-impact damage
Response	PSAP, ambulance, hospital, police, contacts	Dispatch and coordinate assistance	Interoperability and workflow
Data	Cloud, dashboard, database, mobile app	Monitoring, logging and analytics	Privacy and cybersecurity

IV. ACCIDENT DETECTION TECHNOLOGIES

Accelerometers are the most common crash-detection sensors because collisions produce rapid changes in acceleration. Three-axis MEMS devices are inexpensive and can detect both magnitude and direction of shock. However, a single acceleration threshold is not sufficient for robust operation. Potholes, hard braking, curb strikes, dropping a smartphone, or rough roads can generate large transient signals. Conversely, some serious crashes may involve complex multi-stage dynamics rather than a single extreme peak. Thresholds must therefore be selected carefully and ideally adapted to vehicle type and operating conditions.

Gyroscopes complement accelerometers by measuring angular velocity. They are particularly valuable for rollover detection and for distinguishing ordinary longitudinal braking from abnormal rotational motion. Vibration sensors provide another inexpensive indication of impact, while ultrasonic sensors have been used in prototypes to detect obstacle proximity. Vehicle-native information such as airbag deployment, wheel speed, steering angle, brake status and OBD-II parameters can further improve confidence because these signals describe the vehicle state directly. A major advantage of sensor fusion is that a decision can require agreement between several independent indicators rather than relying on one noisy measurement [5], [12].

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Machine learning is increasingly used to replace or supplement fixed thresholds. Classification algorithms can learn patterns associated with crashes, harsh braking, normal cornering and road irregularities. Smartphone research has examined intelligent accident classification, while more recent transportation studies investigate support-vector machines, convolutional neural networks and computer-vision methods for accident recognition [11], [13]. Machine learning can improve discrimination when representative training data are available, but real crash data are difficult and ethically challenging to collect. Models trained mainly on simulations or controlled experiments may not generalize to different vehicle masses, suspension systems, phone orientations, road surfaces and collision types.

An emerging direction is multimodal detection. Inertial signals can be combined with camera information, audio, vehicle speed and contextual data. Visual systems can identify damaged vehicles or abnormal traffic scenes, while connected infrastructure can corroborate an onboard alert. Such approaches may improve accuracy and also provide responders with information about the accident environment. Nevertheless, additional sensors increase computation, cost, energy demand and privacy exposure.

V. LOCATION, COMMUNICATION AND NOTIFICATION

Accurate location is indispensable because a rapid alert is of limited value if responders cannot find the crash. GPS/GNSS modules are widely used to provide latitude and longitude and can also supply speed and time. Their main limitations are signal blockage in tunnels, underground structures and dense urban environments. Hybrid positioning using cellular networks, inertial dead reckoning, map matching or connected infrastructure can provide fallback capability when satellite positioning is degraded.

GSM-based SMS remains common in low-cost prototypes because it is simple, widely supported and does not require a continuous Internet session. Many studies send a map link or coordinates to family members and emergency personnel [3], [6], [9]. Packet-based IoT communication provides richer data, real-time dashboards and two-way acknowledgement. GPRS, LTE and 5G can transmit sensor histories, images and video, while MQTT and cloud services facilitate lightweight machine-to-machine messaging. A dual-channel strategy is attractive: if Internet data are unavailable, an SMS or voice call can still be attempted. Recent systems explicitly use redundant GSM and Internet channels for this reason [6].

Notification quality matters as much as transmission speed. An emergency message should be concise and structured: event type, confidence or severity, location, time, vehicle identity, direction of travel and a callback channel. Too little information forces dispatchers to reconstruct the event; too much unstructured information can slow interpretation. The eCall Minimum Set of Data is a useful example of standardized, machine-readable emergency information [8]. Future research should emphasize compatibility with dispatch software rather than only demonstrating that an SMS can be sent.

VI. EMERGENCY RESPONSE AND RESCUE COORDINATION

A complete response system begins after the alert is received. The receiving platform should verify the event, locate appropriate resources and support dispatch. In research prototypes, the recipient is often a family member or a generic emergency contact. This is useful for proof of concept, but real deployment requires integration with public emergency services, ambulance control rooms, hospitals and police. The receiving organization must know the alert source, trust the device, interpret the data, and communicate back to the vehicle or caller when necessary.

Severity estimation can improve resource allocation. A low-confidence minor event may justify confirmation, whereas a high-energy collision with rollover or airbag deployment may require immediate ambulance, fire and police response. Automatic triage could consider peak acceleration, change in velocity, rollover, vehicle type, number of occupants and available medical data. Aslam et al. highlighted the value of visual situation reporting because rescuers benefit from understanding the state of vehicles and victims before arrival [5]. Similar concepts could use images from an onboard camera or a witness application, subject to privacy and bandwidth controls.

Response coordination should also include acknowledgement and escalation. The vehicle should know whether the emergency center received the message. If acknowledgement fails, the system can retry through another network or notify secondary contacts. Location updates may be useful if a vehicle moves after the initial event or if a crash

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involves hazardous terrain. Event logs can later support quality assurance, crash investigation and improvement of detection algorithms.

VII. REVIEW OF REPRESENTATIVE RESEARCH

The reviewed literature reveals several recurring design families. Arduino-based systems emphasize affordability and ease of prototyping. They typically integrate a MEMS accelerometer or vibration sensor with GPS and GSM, and demonstrate automatic SMS notification [3], [9]. Raspberry Pi and cloud-oriented systems provide more processing capability and can support severity assessment and remote monitoring [4]. ESP32 platforms have become increasingly popular because they combine strong embedded processing with wireless connectivity at low cost [5], [6].

Smartphone-centric studies exploit existing consumer hardware. They can combine inertial sensors, GNSS and cellular communication, and some systems incorporate OBD-II data or allow the driver to cancel a false alarm [10], [11]. Their principal advantage is scalability without permanent vehicle hardware, whereas dedicated embedded units offer controlled sensor placement and can be integrated with vehicle power and safety systems.

The literature also shows a transition from notification to response intelligence. Earlier work mainly answered two questions: “Did a crash occur?” and “Where is the vehicle?” Newer work asks additional questions: “How severe is the crash?”, “What information does the responder need?”, “Was the alert delivered?”, “Can another channel be used?”, and “Can the emergency center visualize the situation?” The 2024 IoT visual reporting system and recent dual-channel designs illustrate this transition [5], [6]. A 2025 review of IoT approaches similarly identifies accelerometers, GPS, GSM, mobile devices and intelligent classification as central themes and emphasizes the need for reliable integration [14].

Table 2. Comparison of major ANRS approaches

Approach	Strength	Limitation	Typical alert	Best use
Threshold embedded	Simple, fast, inexpensive	Sensitive to threshold choice	SMS/call	Low-cost retrofit
Smartphone based	Uses existing sensors/connectivity	Mounting, battery, OS dependence	App/SMS/data	Mass-market supplementary safety
IoT/cloud	Rich monitoring and analytics	Internet and server dependence	Cloud + SMS/data	Fleet and connected transport
Sensor-fusion/ML	Better contextual discrimination	Training data and computation	Structured event packet	Advanced crash classification
Standardized eCall	Direct emergency-service integration	Requires infrastructure/standards	Voice + minimum dataset	Production vehicles and public safety

VIII. CHALLENGES AND LIMITATIONS

False alarms are one of the most important technical barriers. Emergency centers cannot accept systems that repeatedly report potholes or abrupt maneuvers as crashes. False negatives are equally serious because a missed severe accident defeats the purpose of automation. Robust detection therefore requires representative validation, adaptive thresholds, sensor fusion and a carefully designed cancellation mechanism. Testing only with small prototype vehicles or manually generated impacts is insufficient evidence for road deployment.

Communication reliability is another challenge. Cellular coverage varies geographically, and severe impacts can damage vehicle power, antennas or communication modules. Systems should incorporate backup energy, store-and-forward capability and multiple communication paths where practical. GNSS can also fail in tunnels or urban canyons, so fallback localization is desirable. Emergency systems must remain functional during the abnormal conditions for which they are designed, not merely during laboratory demonstrations.

Cybersecurity and privacy become increasingly significant as systems connect to the cloud. Accident packets may contain precise location, vehicle identity, owner details and possibly health information. Authentication is required to prevent false emergency messages, while encryption and access control are needed to protect personal data. At the

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same time, security procedures must not introduce unacceptable delay or make the system unusable when connectivity is poor.

Interoperability is perhaps the largest system-level challenge. A technically successful detector does not automatically produce an effective rescue response. Different regions use different emergency numbers, dispatch software, data formats and institutional workflows. Standardization of event data, device identity, acknowledgement, severity coding and interfaces is necessary for scalable deployment. The eCall model demonstrates the advantage of designing vehicle and emergency infrastructure together [8].

Finally, cost and maintenance affect adoption. Sensors may drift, SIM subscriptions may expire, batteries degrade, and software must be updated. A practical ANRS requires self-diagnostics and periodic health checks. Fleet applications can support centralized maintenance, whereas private vehicles require a low-maintenance design with clear failure indication.

IX. FUTURE RESEARCH DIRECTIONS

Future ANRS research should move from isolated prototypes toward validated, interoperable safety platforms. First, edge artificial intelligence can process multi-sensor data locally, reducing cloud dependence and enabling rapid classification. Models should be trained using diverse driving data and evaluated across different vehicle categories, road conditions and crash configurations. Explainable decision logic may be particularly valuable in safety-critical applications because developers and emergency agencies need to understand why an alert was triggered.

Second, V2X and next-generation cellular communication can provide redundancy and context. A crashed vehicle may notify nearby vehicles or roadside units even when direct Internet connectivity is weak. Connected infrastructure could relay the alert, warn approaching traffic and provide responders with lane-level location. Third, future systems should estimate injury and rescue requirements rather than merely collision occurrence. Integration with airbag systems, seat-belt status, occupant detection and wearable health sensors could support more informed triage, provided privacy is protected.

Fourth, digital maps, cloud analytics and emergency-resource databases can support automatic selection of the nearest appropriate ambulance, trauma center or police unit. Response platforms should include acknowledgement, escalation and audit trails. Fifth, multimodal scene reporting using cameras or witness applications may improve situational awareness, but should be activated selectively to manage bandwidth and privacy. Finally, international and national standards should define minimum performance requirements for detection accuracy, alert latency, location accuracy, power resilience, cybersecurity and interface compatibility.

A particularly important research need is realistic validation. Controlled crash-test data, naturalistic driving datasets, hardware-in-the-loop simulation and cooperation with emergency agencies can provide stronger evidence than benchtop demonstrations alone. Evaluation metrics should include sensitivity, specificity, false-alarm rate, detection latency, notification latency, location error, message-delivery success and end-to-end response time.

X. CONCLUSION

Accident notification and response systems have evolved from simple impact-triggered SMS devices into connected, multi-sensor emergency platforms. The fundamental architecture remains consistent: detect abnormal crash dynamics, confirm the event, determine location, transmit a reliable notification and support rapid rescue. Accelerometers, gyroscopes, vibration sensors, GPS/GNSS and GSM remain the technological foundation of many systems, while IoT connectivity, cloud services, smartphones, sensor fusion and machine learning are extending their capability.

The literature indicates that the most important improvement is a change in design perspective. Accident detection should not be treated as an isolated electronics problem; it is the first stage of an end-to-end emergency-response workflow. Real benefit depends on accurate detection, low false-alarm rates, resilient communication, standardized information, integration with emergency control rooms and appropriate dispatch. The European eCall system demonstrates the value of direct interoperability, while recent research on visual reporting and redundant communication points toward richer and more dependable future solutions.

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Future ANRS platforms should therefore combine intelligent edge detection with redundant connectivity, secure data exchange, fallback localization, severity estimation and responder-oriented information. With rigorous validation and institutional integration, these technologies can reduce the time between a road crash and effective medical assistance and can become a significant component of safer intelligent transportation systems.

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