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A Review on Solar Energy–Driven Sensor Architectures for Accident Detection and Vehicle Monitoring

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Abstract: The increasing rate of road accidents and the limitations of traditional vehicle monitoring systems have increased the demand for real-time, reliable, and energy-efficient safety solutions. An alternative that is considered to be sustainable is the sensor architecture that is operated using solar energy since it allows the device to operate on its own without the need to rely on vehicle batteries or a grid power source. The current review is a systematic study of available solar-powered sensor architecture developed so far to be used in the accident detection and vehicle monitoring. The analysis of the research is based on the significant system elements such as energy harvesting and storage units, sensing modules, processing and control units, and communication technologies. The importance of multi-sensor integration, energy efficiency, accuracy of detection, and reliability of the system is emphasized. The comparison of solar and hybrid solar-battery systems to traditional power sources presented in tables and performance-based numbers shows the benefits of the system, and the enhanced accuracy of sensor fusion techniques. The current challenges like energy variability, false alarms, and constraints of communication are also addressed in the review, with future research directions of greater scalability, intelligence, and robustness of solar-powered vehicular safety systems.

Keywords: Solar Energy, Accident Detection, Vehicle Monitoring, Sensor Architectures, Iot, Intelligent Transportation Systems.

1. INTRODUCTION

The rapid increase in vehicular traffic is an international problem that has greatly contributed to road accidents, traffic congestion and environmental issues. Road accidents, according to statistics on global transportation are one of the major causes of deaths particularly in the developing nations. One of the factors that contribute much to the severity of an accident is the delay in detecting the accident and responding to the emergency, which most of the time occurs due to lack of real-time monitoring systems.

The conventional systems of vehicle monitoring and accident detection presuppose extensive battery of vehicles or power lines. Such systems are vulnerable to power failures, need regular servicing and are not suitable in remote or rural areas. Further, more and more Internet of Things (IoT)-based transportation solutions require energy-efficient and self-sustainable power sources.

Sensor architectures powered by solar energy would be an effective option as the technologies of renewable energy collection would be integrated with intelligent sensing and communication technologies., Solar-powered systems enable continuous 24/7 operation lower cost of operation and environment friendliness. These architectures can be used to solve the problem of real-time accident detection and vehicle monitoring, which does not necessitate traditional power sources because they incorporate photovoltaic panels, sensors, microcontrollers, and wireless communication modules.

This review paper will critically examine the current solar-powered sensor architectures in accident detection and vehicle monitoring, their design strategies, functionality features, issues, and the future research potential.

This review paper differs from prior review papers on accident detection via the IoT and solar power-based vehicular safety monitoring systems since it examines these technologies together. This study paper also provides insights into the existing gaps in research in the domain, performance challenges, and possibilities for the future of sustainable intelligent transportation.

2. REVIEW METHODOLOGY

This systematic literature review focused on analyzing the recent progress in the architecture of solar-powered sensor systems designed for accident detection and vehicle monitoring applications. Literature sources from 2018 to 2025 relevant to the topic under consideration were retrieved from various databases, namely IEEE Xplore, Scopus, ScienceDirect, SpringerLink, and Google Scholar, with the help of key terms like “solar-powered sensors,” “accident detection,” “vehicle monitoring,” “IoT transportation systems,” and “sensor fusion.” Research articles and conference papers associated with intelligent transportation and renewable energy monitoring systems were considered, whereas irrelevant and repetitive documents were ignored.

3. LITERATURE REVIEW

Advances in the intelligent transport system have led to increasing interest in IoT-based accident detection, solar power-based monitoring, and vehicle communication technology. Earlier researchers have concentrated on enhancing detection reliability, energy consumption, and real-time monitoring by using sensors and renewable energy sources. This paper examines some important studies conducted in the field of these technologies and highlights current research gaps.

3.1 IoT-Based Accident Detection Systems

Alvi et al. (2020) conducted research in order to explore the issue of accident detection in smart cars using IoT technology. They have examined several methods used to detect accidents with the help of accelerometer, gyroscope, GPS module, and cloud communication system technologies. However, the research has found some issues, such as power consumption, unnecessary alerts, and dependence on batteries of vehicles.

Kumar et al. (2020) designed a vehicle accident detection and classification system based on Internet of Things (IoT), utilizing sensor fusion technology. This research showed that sensor fusion considerably improved system reliability than the single-sensor technique. However, there was a downside to their architecture; it demanded more computation and energy consumption.

Mateen et al. (2022) proposed intelligent road infrastructures for automatic accident detection and warning systems. The study was based on an intelligent transport system scenario in which sensors, communications equipment, and automated warning systems worked together to enhance road safety. They found that intelligent road infrastructure could be useful in handling accidents promptly and managing traffic efficiently. But problems such as high costs and communication reliability persisted.

In summary, IoT-based accident detection systems available currently offer efficient monitoring and response services. Nonetheless, most systems rely excessively on traditional sources of energy, thus being constrained by energy inefficiency, delay in communication, and unnecessary false alarms.

3.2 Solar-Powered Monitoring and Energy Harvesting Systems

Aghaei et al. (2025) provided a comprehensive multidisciplinary analysis of autonomous intelligent monitoring systems used in photovoltaic (PV) systems. The authors discussed the intelligent monitoring system architecture, fault identification techniques, and energy management within solar-based systems. This research highlighted the importance of renewable energy-based monitoring systems.

Sharma et al. (2018) examined solar energy harvest methodologies for use in wireless sensor network nodes. The paper examined different ways of converting solar energy into usable electrical energy in a wireless sensor network node. The authors found that energy harvest from solar sources greatly increased system longevity and reduced maintenance costs.

Solomon et al. (2024) developed an innovative model of solar-powered autonomous vehicles that incorporate object recognition and evasion capabilities with the help of Raspberry Pi. It showed the potential practicality of the integration of solar-powered systems with sensing capabilities in transportation. Yet, the environmental elements like the amount of sunlight and weather dependence became significant constraints on system efficiency.

The findings of the studied papers show that solar energy is a sustainable and energy-efficient approach for ITSs. Nevertheless, there are issues concerning energy fluctuations, efficient energy storage, and dependence on the environment that should be investigated further.

3.3 Communication Technologies and Sensor Fusion Approaches

Ahmed Amin et al. (2025) conducted an extensive review of intelligent vehicular and sensor communication networks. They examined the structure of vehicular-to-vehicular (V2V) and vehicular-to-infrastructure (V2I) communication systems, wireless communication techniques, and data transfer procedures in intelligent transportation systems. They found that a dependable communication network was vital for implementing real-time collision detection and vehicular tracking.

Roopini et al. (2024) proposed IoT architecture was driven by Artificial Intelligence to prevent and detect accidents with vehicles. The research considered the use of artificial intelligence, IoT communications technology, and cloud computing to optimize system responses and improve detection capabilities. It exhibited improved efficiency, although computation complexity and dependence on the network were significant challenges.

Tahir et al. (2024) examined object detection methods for autonomous cars under difficult weather situations. The researchers made a comparison between conventional computer vision and object detection using deep learning. They found that although deep learning provides more accurate object detection, it consumes high computation resources.

The reviewed literature indicates that the use of communication technology and sensor fusion techniques plays an important role in improving the effectiveness of intelligent vehicular systems. However, problems like communication delay, heavy computation, and instability of networks pose challenges in making real-time monitoring effective.

Table 3: Comparative Analysis of Existing Studies on Solar-Powered Accident Detection and Vehicle Monitoring Systems

Study	Methodology	Key Technology	Major Contribution	Limitation
Alvi et al. (2020)	IoT-based accident detection	Sensors + Cloud	Real-time accident alerts	High power consumption
Kumar et al. (2020)	Sensor fusion system	Multi-sensor integration	Improved detection accuracy	Increased computational complexity
Mateen et al. (2022)	Smart road infrastructure	Autonomous warning system	Enhanced traffic safety	High infrastructure cost
Aghaei et al. (2025)	PV monitoring review	Solar-powered monitoring	Improved sustainability	Complex system integration

Solomon et al. (2024)	Solar autonomous vehicle prototype	Raspberry Pi + Object Detection	Energy-efficient monitoring	Weather dependency
Roopini et al. (2024)	AI-driven IoT framework	Cloud + AI integration	Improved system intelligence	Network dependency

3.4 Research Gaps in Existing Studies

The existing literature largely concentrates either on IoT-based accidents detection systems or on solar-powered energy harvesting systems individually. There is not much work that combines both approaches into one single system. In addition, the existing systems are faced with problems concerning energy variations, communication issues, high computational complexity, and false alarms. More research needs to be conducted on efficient, robust, and scalable solar-based sensor systems to accommodate intelligent transport applications.

4. OVERVIEW OF SOLAR ENERGY–DRIVEN SENSOR ARCHITECTURES

The sensor architectures based on solar power are generally made up of four basic subsystems, which are energy gathering and storage, sensing unit, processing unit, and communication unit.

- ***Energy Harvesting and Storage Unit***

The energy harvesting unit employs photovoltaic (PV) panels that transform solar energy into electricity. The energy harvested is controlled by charge controllers and stored in either rechargeable batteries or supercapacitors. Lithium-polymer and Lithium-ion batteries are very common and have a high-energy density associated with them and also have a long-life cycle.

Maximum Power Point Tracking (MPPT) methods are widely applied in solar-energy systems to optimize the efficiency of solar energy generation in changing levels of sunlight. Charge controllers control power transfer from photovoltaic modules to storage devices in order to avoid overcharging and extend battery life.

- ***Sensing Unit***

The sensing unit will involve the gathering of real-time information that has reference to vehicle movement, impact, position, and environmental factors. The common sensors are the accelerometers, gyroscopes, vibration sensors, GPS modules, ultrasonic sensors, cameras. Such sensors are important in sensing accidents, tracking the behavior of vehicles, and issue warnings.

- ***Processing and Control Unit***

The processing unit consists of microcontrollers or embedded processors such as Arduino, ESP32, or Raspberry Pi. This unit processes sensor data using predefined thresholds, rule-based logic, or machine-learning algorithms to identify abnormal events such as collisions or sudden braking.

Modern edge computing methods have been extensively incorporated into embedded systems in order to perform on-site computations. The use of edge computing methods enhances real-time accident detection capabilities while minimizing the reliance on cloud-based networks.

- ***Communication Unit***

Communication unit facilitates the exchange of information between the vehicle and the outside systems. Relying on GSM, GPS, LTE, LoRa, ZigBee, and Wi-Fi technologies, it is not uncommon to pass data on accidents, vehicle whereabouts, and monitoring to an emergency service or cloud-based services.

5. SOLAR-POWERED ACCIDENT DETECTION SYSTEMS

Solar-powered accident detection systems are designed to detect any accident and send a notification to the emergency department. These systems are normally based on abrupt acceleration, vibrations or orientation.

Table 1: Comparison of Sensors Used in Solar-Powered Accident Detection Systems

Sensor Type	Function	Advantages	Limitations
Accelerometer	Detects sudden acceleration/deceleration	Low cost, low power	Sensitive to noise
Gyroscope	Measures angular motion	Improves rollover detection	Higher power usage
Vibration Sensor	Detects physical impact	Simple and fast	Limited precision
GPS	Provides location data	Essential for emergency response	Signal loss in tunnels

The most popular of them is accelerator-based detection because it consumes less power and is simple. There are however false alarms that can be as a result of potholes or sudden braking. Modern systems combine several sensors and use sensor fusion methods in order to enhance reliability.

The modern detection systems for accidents use sensor fusion methods whereby data from accelerometers, gyroscopes, and GPS receivers are combined to enhance detection and minimize false alarms. Machine learning is also used to differentiate accidents from sudden braking and road hazards.

Threshold-based systems are commonly applied owing to their minimum computing costs; yet, AI-based intelligent systems offer better adaptability and reliability in difficult situations encountered while driving.

6. SOLAR-BASED VEHICLE MONITORING ARCHITECTURES

Vehicle monitoring systems track parameters such as speed, location, driving behavior, and vehicle health. Solar powered monitoring architectures are especially useful in fleet management, the public transport and long-haul vehicles.

Table 2: Communication Technologies Used in Solar Vehicle Monitoring Systems

Technology	Range	Power Consumption	Typical Application
GSM	Long	Medium	Emergency alerts
GPS	Global	Medium	Vehicle tracking
LoRa	Very long	Low	Rural monitoring
ZigBee	Short	Very low	In-vehicle communication

High-end vehicle surveillance systems facilitate V2V and V2I communication for effective transmission of information. Low-energy communication technologies like LoRa enable long-distance communication with low energy expenditure, thus making them ideal for surveillance applications in rural areas.

Solar energy also enables continuous monitoring even when there are vehicles that are on idle situations. Cloud services enable the saving of data, its visualization, and analysis using IoT-based platforms.

The IoT cloud platform allows for storing data in real-time, data visualization, predictive analytics, and remote monitoring. The integration of AI into cloud computing helps improve traffic analysis and driver behavior prediction.

7. PERFORMANCE ANALYSIS AND COMPARATIVE EVALUATION

Evaluations of the solar energy-based sensor architecture are based on the following parameters: energy efficiency, accuracy of detection, latency, and reliability of the system.

Solar-powered systems have much better operating life than battery-only powered systems, particularly in a continuous monitoring environment. Hybrid solar-battery designs also contribute to reliability by addressing the differences in the sunlight availability.

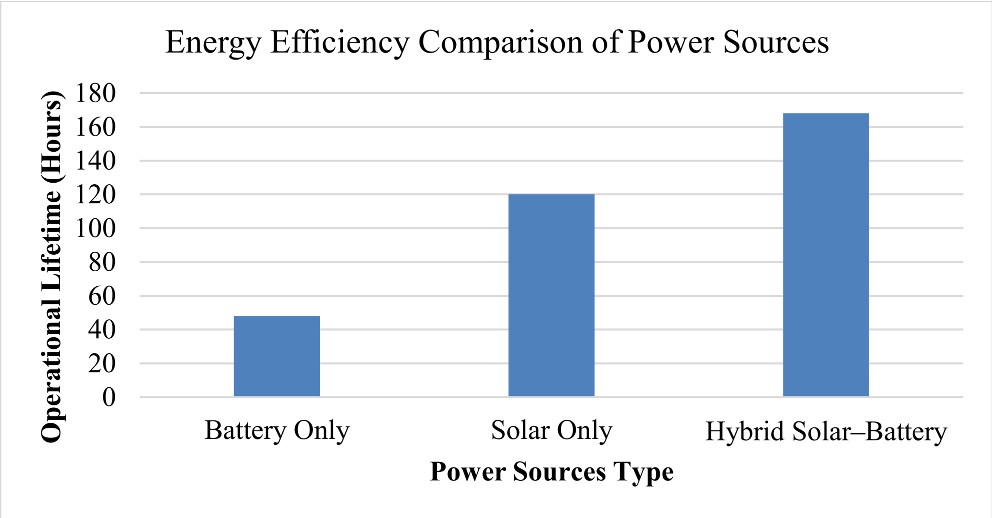

Figure 1: Energy Efficiency Comparison of Power Sources

Figure 1 shows the energy efficiency comparison of different types of power sources used for vehicle surveillance and accidents detection devices. Systems that use battery sources only have the shortest operating life due to their inability to store high amounts of energy. Those powered by solar energy have a much longer life span compared to others since they rely on sustainable sources of energy.

The literature indicates that multi-sensor fusion systems are more effective than single- sensor based systems in detecting the target and reducing false alarms, but with computational complexity.

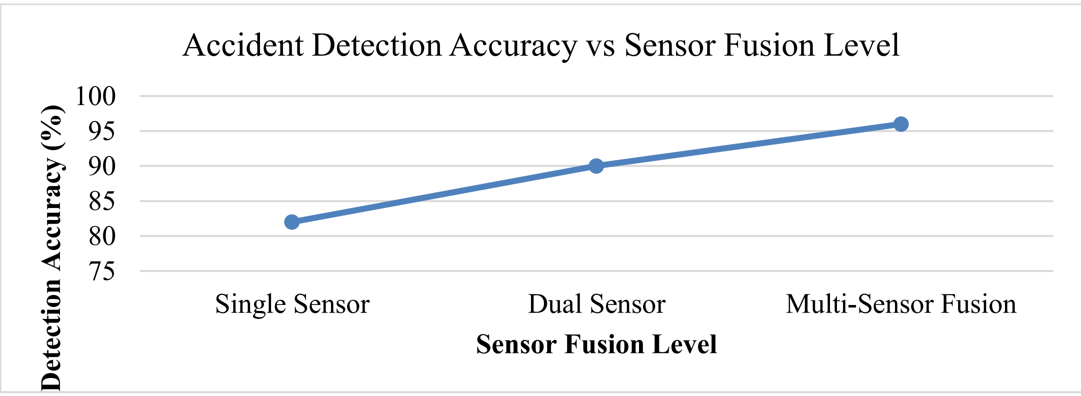

Figure 2: Accident Detection Accuracy vs. Sensor Fusion Level

Figure 2 indicates that the accuracy of accident detection increases with higher sensor fusion levels. Single-sensor-based approaches have more chances of being affected by noise and false alarm generation, leading to low accuracy rates. The dual-sensor approach is more reliable compared to single-sensor approaches, but multi-sensor fusion offers the best accuracy rates of accident detection by combining different sensors' information.

8. CONCLUSION

Solar power sensor networks can be seen as a sustainable and promising solution to accident detection and vehicle monitoring in the modern transport systems. As noted by this review, the incorporation of photovoltaic energy collection with intelligent sensing and processing and communication units offers a much higher level of autonomy, extended system lifespan, and reliability than those that rely on batteries. It has been found in the analysis of performance that hybrid solar-battery systems are more efficient in energy use whereas multi-sensor fusion systems can significantly enhance the accuracy of accident detection and decrease false alarms. Although these are the strengths, there are other challenges that still exist like the variability of solar energy, complex computations and communication constraints. The management of these problems by complex energy efficiency and management schemes, aids to detect them by using artificial intelligence, and a strong communication system will be instrumental in future progress. In general, solar-powered sensor architecture can be very effective in providing safer, smarter and sustainable systems. Further studies should be conducted towards the implementation of AI, edge computing, and energy management into solar-powered vehicular monitoring systems. More enhancements on sensor fusion, wireless communication systems, and predictive analysis would make this new-age intelligent transportation system more reliable, scalable, and precise in detecting any accidents that might happen.

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