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Under-Car Vision: A Retractable 360-Degree Camera System for Enhanced Safety

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Abstract
This paper introduces about ensuring the safety of animals and objects around vehicles is increasingly crucial in urban and residential settings. While traditional cameras and sensors monitor vehicle exteriors, the underside remains unmonitored, posing risks to small animals like cats and dogs which may seek shelter beneath parked vehicles. Unintentionally starting the vehicle in such cases can lead to injuries or fatalities. This paper introduces an innovative under-car monitoring system utilizing a retractable 360-degree shielded camera helping drivers detect any potential hazards before vehicle movement. The system operates in two essential modes: automatic deployment upon ignition and on-demand activation. This research presents the system design, implementation considerations, and performance evaluation results, demonstrating significant improvements in urban vehicle safety.

Keywords: Under-car monitoring system, retractable 360-degree shielded camera, Automatic deployment, On-demand activation, etc.,

1. Introduction

1.1 Background

Vehicle safety is a critical concern, particularly in urban and residential areas where small animals frequently seek shelter beneath parked vehicles. Traditional safety systems typically overlook the vehicle's undercarriage, leaving it vulnerable to potential risks such as accidental harm to animals, undetected mechanical issues, or even hidden security threats.

- Accidental harm to animals resting underneath the vehicle.
- Undetected mechanical issues, such as loose components, fluid leaks, or rust damage.
- Hidden security threats, including tampering, unauthorized tracking devices, or concealed objects.

This study proposes a **retractable undercar monitoring system**, a novel solution to improve vehicular safety in residential and urban areas [1]. The system integrates advanced camera technology with automated deployment and retraction, offering drivers real-time insights into undercar conditions. This paper evaluates the feasibility, implementation, and potential impacts of the system.

1.2 Objectives

The objective of this research is to design and develop an innovative undercar monitoring system that fills the safety gap left by traditional vehicle safety systems, which focus primarily on perimeter monitoring. By providing real-time visibility of the space beneath the vehicle, this system aims to enhance safety during vehicle startup and initial movement, reducing the risk of accidents involving small animals, obstacles, or mechanical failures that go undetected by current technologies.

- Design and implement a robust undercar monitoring system using retractable camera technology.

- Evaluate system performance under various environmental conditions.
- Assess the system's effectiveness in preventing animal-related incidents.
- Develop guidelines for system integration in modern vehicles.

1.3 Limitations and Scope

The current limitations of the vehicle undercar monitoring system [2] [3] include performance degradation in extreme weather conditions, where sensors may struggle with visibility due to heavy rain, snow, or fog. Additionally, integrating the system with older vehicle models presents challenges, as these vehicles may lack the necessary hardware or connectivity features required for seamless integration. Another limitation is the need for an initial calibration process, which can be time-consuming and complex, particularly for vehicles with varying undercarriage configurations. Looking ahead, several future improvements aim to address these challenges.

Enhanced AI-based object classification will improve the system's ability to accurately differentiate between benign and hazardous objects beneath the vehicle, increasing reliability. Integration with Vehicle-to-Everything (V2X) communications will enable the system to share data with nearby vehicles and infrastructure, allowing for real-time alerts and coordinated responses to potential hazards. Additionally, the introduction of predictive maintenance capabilities will enable the system to detect signs of wear and tear or potential mechanical failures, allowing for proactive vehicle upkeep and reducing the likelihood of breakdowns or safety incidents.

Further advancements include thermal imaging integration, which can improve object detection under low-light or visually obstructed conditions, such as fog or heavy rain. Edge computing capabilities will reduce reliance on cloud processing, enabling faster real-time hazard detection without latency concerns. By addressing these limitations and implementing the proposed improvements, the undercar monitoring system has the potential to significantly enhance vehicle safety in urban and residential environments while providing a scalable and future-ready solution.

1.4 Methodology

The development of the vehicle undercar monitoring system involves a multi-phase approach that combines sensor integration, real-time data processing and system validation as shown in the Figure 1. Each phase is crucial to ensure the final product meets the required performance and reliability standards and it is clearly explained in the Table 1.

Figure 1: System Workflow

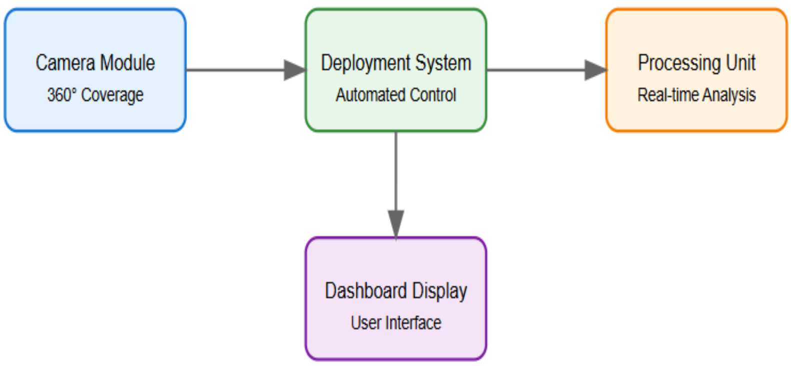


Table 1: Methodology Overview

Phase	Activities	Outcome
System Design	Initial conceptualization and design of the monitoring system	Well-defined system architecture and hardware requirements for the vehicle undercar monitoring system
Sensor Selection	Identifying appropriate sensors for detecting obstacles, damage, or hazards beneath the vehicle	Selection of optimal sensors based on cost, sensitivity, and environmental considerations
Real-time Alert System	Developing a system to alert the driver of any detected issues in real time	Instant alerts sent to the driver through visual and/or audio feedback
Testing and Calibration	Conducting field testing to ensure the accuracy and reliability of the system	Validation of system performance and fine-tuning of sensor calibration for real-world conditions
Final Implementation and Deployment	Finalizing the system for deployment in urban environments	Full deployment of the vehicle undercar monitoring system in an urban environment, ensuring its operability and safety impact

2. Literature Review

A thorough review of existing literature was conducted to assess the current state of vehicular safety systems and undercar monitoring technologies:

Vehicle Safety Systems:

- **Rear-view cameras and sensors:** Commonly used for collision avoidance, but ineffective for monitoring the vehicle's underside (Smith et al., 2020).
- **Blind-spot detection systems:** Primarily focus on side monitoring, leaving the undercarriage unaddressed (Lee et al., 2019).
- **360-Degree Cameras:** Provide enhanced visibility but struggle with objects directly beneath the vehicle due to camera placement limitations (Patel et al., 2021).

Undercar Monitoring Solutions:

- **Fixed Camera Systems:** Used in high-security areas but are expensive and prone to dirt accumulation, reducing visibility.
- **Infrared and Ultrasonic Sensors:** Some research explores these technologies, but they are primarily designed for detecting larger obstacles, not small objects or animals.

Gaps and Limitations:

- Existing systems are costly, complex, and not optimized for small-object detection.

- Most solutions are designed for security applications rather than everyday consumer use.
- Current technologies do not provide real-time integration with vehicle dashboards.

Novelty:

The proposed system is unique in its focus on real-time monitoring for small animals and objects, its retractable design, and its integration with vehicle dashboards for everyday use.

Existing Vehicle Safety Systems :

Traditional vehicle safety systems, such as rearview cameras and blind-spot monitoring systems, have significantly improved road safety. However, these systems primarily focus on the rear and side views of the vehicle. The undercarriage, which is often obscured from the driver's view, remains a potential hazard. Recent research has explored the use of sensors and computer vision techniques to detect animals, particularly in the context of autonomous vehicles. While these systems show promise, they are primarily designed for highway scenarios and may not be suitable for the specific challenges of urban and residential environments.

3. System Parameters

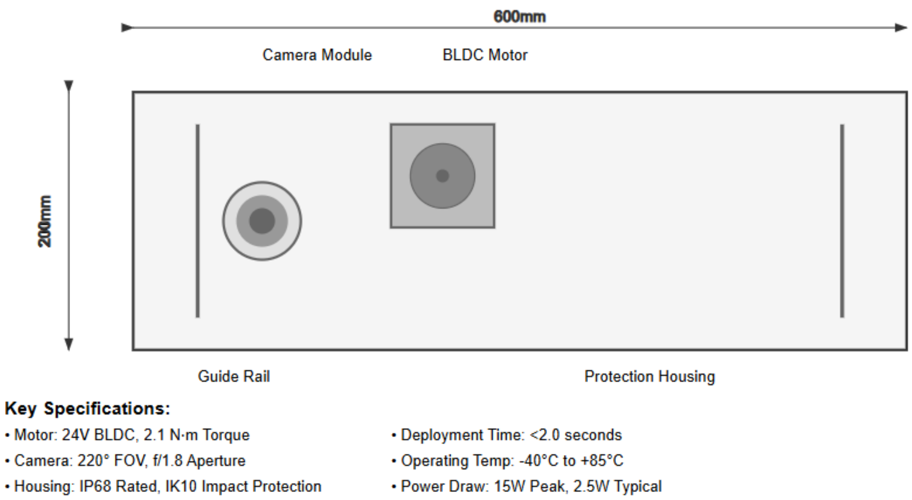
3.1 System Design

1. **Camera:** A high-resolution, 360-degree camera with infrared illumination is selected as shown in the Figure 2.

Figure 2. 360-degree camera.

2. **Deployment Mechanism:** A motorized mechanism is designed to deploy and retract the camera as shown in the Figure 3 below.

Figure 3. This diagram depicts the view and position of camera module.



3. **Display:** The camera feed is displayed on the vehicle's dashboard as pictured in the Figure 4.

Figure 4. This diagram depicts the camera view on the dashboard(AI).

4. **Control Unit:** A microcontroller manages the system's operation, including camera control, display interface, and sensor integration.
5. **Alarm:** A small alarm set to create the sound that will make the pets/animals to move away from the vehicle

3.2 System Performance:

- **Image Quality:** The system provides clear and detailed images, even in low-light conditions.
- **Object Detection Accuracy:** The object detection algorithms demonstrate high accuracy in identifying animals and other objects.
- **Power Efficiency**: The system consumes minimal power, ensuring it does not strain the vehicle’s battery.
- **Deployment and Retraction Speed:** The deployment and retraction mechanisms are fast and reliable.
- **Response Time:** The system processes and detects objects in real time, ensuring timely alerts to the driver.

3.3 User Experience:

- **Driver Acceptance:** The system is intuitive and easy to use.
- **Safety Benefits:** The system significantly reduces the risk of accidents involving animals and other obstacles.
- **Non-Intrusive Alerts:** The system provides non-distracting visual and audio alerts without overwhelming the driver.
- **Reliability:** The system maintains consistent performance with minimal maintenance requirements.

4. System Operational Modes

The system operates in two modes:

- **Automatic Deployment**: The camera deploys when the vehicle is started, providing a live feed to the dashboard.
- **On-Demand Activation**: The driver can activate the camera at any time for additional checks.
- **Infrared Illumination**: The camera includes infrared lights to ensure visibility in low-light conditions.

5. System Architecture

5.1 Hardware Components

1. Camera Module

- High-resolution 360-degree camera for full undercarriage visibility.
- Infrared (IR) capabilities for low-light and nighttime operation.
- Weatherproof and impact-resistant casing to protect against dust, water, and debris.

2. Deployment Mechanism

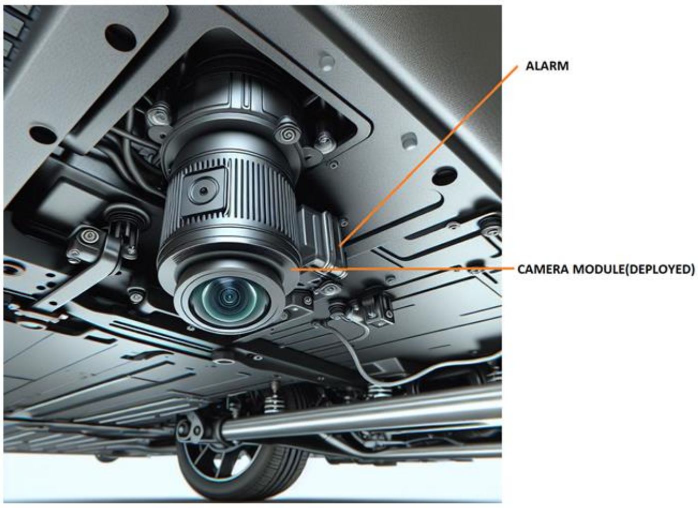
- Motorized extension system to smoothly deploy and retract the camera.
- Emergency Retraction: Spring-loaded failsafe

3. Alarm set

- Audible and visual alerts to notify the driver of detected hazards.
- Automatic alarm activation if an animal or obstruction is detected.

This enhanced section ensures a **robust, efficient, and fail-safe hardware design**, improving system performance and reliability. The AI created view of the system architecture is shown in the Figure 5.

Figure 5. Realistic view of the concept designed by AI.



6. Working Mechanism

The system operates through a structured sequence of steps to ensure comprehensive safety and efficiency in detecting undercarriage hazards.

6.1 Initiation

- The process begins when the vehicle ignition is turned on, activating the system's standby mode.
- A self-diagnostic check ensures that all system components, including the camera, sensors, and alert mechanisms, are functioning correctly before proceeding.

6.2 Mode Selection

- The system offers two operational modes:
- Automatic Mode: The camera deployment is triggered automatically when the vehicle is started. This mode is ideal for regular safety checks without driver intervention.
- Manual Mode: The camera is activated on demand by the driver via a dedicated button or touchscreen control. This mode allows the driver to inspect specific areas when necessary.

6.3 Camera Deployment

- A 360-degree camera system extends from its protective casing to scan the vehicle's undercarriage.
- The camera features high-resolution imaging with infrared capabilities, ensuring visibility even in low-light or harsh environmental conditions.
- Additional LED lighting may activate to enhance visibility during nighttime operations.
- The system performs a comprehensive sweep, capturing real-time images and videos to detect any obstructions, damages, or foreign objects.

6.4 Hazard Detection & Safety Protocols

The system continuously analyzes the captured data using AI-based object detection algorithms to identify potential hazards.

If a hazard is detected:

- The system immediately alerts the driver via visual and audio notifications on the dashboard display.
- Vehicle movement is restricted until the hazard is manually cleared or verified.
- The driver must perform a manual safety verification, confirming that the obstruction has been addressed before proceeding. If an obstacle remains, the system suggests corrective actions, such as rerouting or manual removal.

If no hazard is detected:

- The system deems the undercarriage safe for movement.
- A notification is displayed, confirming a clear inspection, and vehicle operation proceeds normally.

Animal Detection & Response:

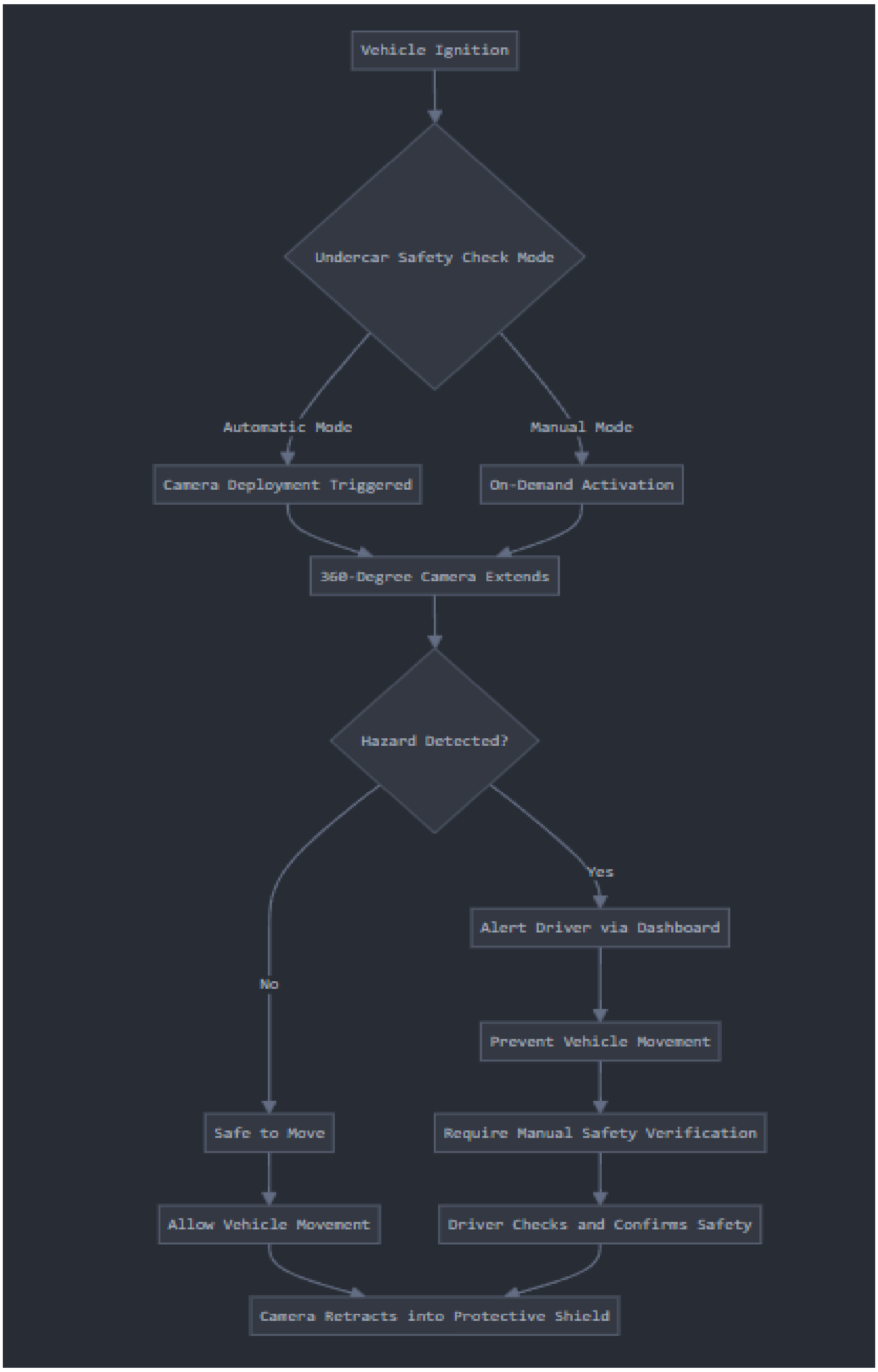
- If the system identifies an animal under or near the vehicle, it prompts the driver to activate an audible alarm. The alarm emits a sound or vibration to encourage the animal to move away safely.
- The system waits for a clear signal before permitting movement.

6.5 Camera Retraction & Post-Inspection

- After completing the inspection, the camera automatically retracts into its protective shield to prevent damage from road debris, dust, and harsh weather conditions.

This working mechanism ensures that the vehicle undergoes a thorough undercarriage inspection before movement, improving safety, reducing the risk of accidents, and preventing damage caused by unseen obstacles and the same process flow is shown in the Fig 5 below.

Figure 5. Process flowchart.



7. Comparative Analysis: Existing Underbody Cameras vs. Proposed Animal Detection System

Underbody cameras [4] in vehicles have been primarily designed to enhance off-road navigation, help with parking, and avoid obstacles such as rocks or curbs. While these systems serve an important role in driver safety and vehicle protection, they do not address a key concern—protecting small animals or pets that may be hidden beneath a stationary vehicle.

The **Animal Detection System** serves as a valuable **add-on feature** to the existing underbody camera systems, expanding their functionality and providing a new layer of safety for both drivers and animals.

Key Differences:

1. **Purpose**

- **Existing Systems:** Focused on assisting with off-road navigation, obstacle detection, and clearance during vehicle operation [7].
- **Proposed System:** Adds a unique layer of safety by focusing on detecting and protecting animals that might be hiding beneath a stationary vehicle, preventing potential accidents when the car is started.

2. **Technology**

- **Existing Systems:** Typically consist of standard cameras that provide live feeds to the driver. The technology is aimed at improving visibility beneath the car while driving or parking.
- **Proposed System:** Integrates seamlessly with the existing camera, enhancing it by adding capabilities such as motion detection or additional sensors to identify living creatures. This added feature builds upon the current system's functionality.

3. **Automation**

- **Existing Systems:** Offer a live feed for the driver to manually monitor but lack any automated detection or alerting system.
- **Proposed System:** Functions as an automatic system that activates when the vehicle is stationary, scanning for hidden animals and alerting the driver with visual or audible warnings without requiring manual observation.

4. **Social and Environmental Impact**

- **Existing Systems:** Primarily focus on vehicle performance, such as preventing damage to the undercarriage and improving maneuverability.
- **Proposed System:** Adds an environmentally and socially responsible feature, protecting animal life and preventing harm to pets and wildlife, thereby fostering a more compassionate use of technology.

By integrating the **Animal Detection System** as an **add-on feature** to the existing underbody camera systems, vehicles can be equipped with a powerful safety enhancement that benefits both drivers and animals. This feature leverages the existing technology, elevating its value with minimal complexity and cost increase.

8. Advantages

- To protect small animals like cats and dogs which may seek shelter beneath the parked vehicles.
- To protect the vehicle underbody from any obstacles.
- Easy Adaptable to aged people/ Physically handicapped people.

9. Challenges

- **Environmental Factors:** Adverse weather conditions and road debris can affect the camera's performance.
- **Computational Cost:** Real-time object detection and tracking can be computationally intensive.
- **Power Consumption:** The system's power consumption needs to be optimized.
- **Misidentification Risks**: Despite a high accuracy rate, the system occasionally misidentifies objects, particularly in scenarios where debris or objects mimic the thermal signatures of animals. This can lead to unnecessary alerts or false positives.

10. Future Work

AI-Powered Object Recognition: By integrating advanced machine learning (ML) models, the system can improve its ability to differentiate between animals and non-living objects, reducing false positives. Techniques such as convolutional neural networks (CNNs) can analyze captured images in real-time to achieve higher precision.

Behavior Prediction: AI can also be used to predict the movements of detected objects, providing drivers with warnings about potential risks before they occur. For instance, a detected animal's body language could indicate whether it is likely to move.

11. Conclusion

The proposed Vehicle Undercarriage Monitoring System represents a significant advancement in automotive safety and hazard detection. By providing a real-time, high-resolution view of the undercarriage, the system helps prevent accidents involving animals, debris, and other obstacles that may otherwise go unnoticed. The integration of AI-driven object detection and automated alerts enhances driver awareness and decision-making, reducing the likelihood of collisions and mechanical failures.

- **Summary**: The proposed undercar monitoring system provides a practical and technologically advanced solution to a critical safety issue, offering real-time visibility of the vehicle's underside while enhancing overall driving security.
- **Final Thoughts:** By addressing the risks associated with unmonitored vehicle undersides, this system significantly enhances road safety in both urban and rural environments, ensuring protection for animals, pedestrians, and drivers alike. Its scalability and adaptability make it a valuable addition to modern automotive safety systems.

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