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Automatic Braking System: A Low-Cost Prototype for Obstacle Detection and Collision Prevention

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Abstract—*This paper presents the design, development, and evaluation of a cost-effective Automatic Braking System (ABS) prototype tailored for low-speed robotic platforms and educational demonstrations. Utilizing Infrared (IR) proximity sensors, transistor-based relay switching, and a DC gear motor to simulate braking force, the system aims to provide a practical, modular platform for understanding fundamental ABS concepts. The prototype integrates onto a custom-designed Printed Circuit Board (PCB) for improved reliability and compactness. Experimental results demonstrate reliable obstacle detection within a 10–20 cm range and sub-second braking response times. Limitations due to sensor sensitivity, environmental conditions, and system simplicity are analyzed. The paper also situates the prototype within the broader landscape of Advanced Driver Assistance Systems (ADAS), highlighting recent developments in sensor technologies, control algorithms, and vehicular safety systems. Future work directions include incorporating microcontroller-based control, advanced sensing (ultrasonic, LiDAR), and intelligent braking algorithms to enhance applicability toward real-world vehicular platforms.*

Index Terms—*Automatic braking system, infrared sensor, relay module, BC547 transistor, DC gear motor, obstacle detection, vehicular safety, Advanced Driver Assistance Systems, embedded systems, prototype.*

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I. INTRODUCTION

Road traffic accidents remain a leading cause of death and injury worldwide, accounting for approximately 1.3 million fatalities annually [1]. Human factors such as delayed reaction times, distractions, and impaired judgment are responsible for the majority of these incidents. To mitigate such risks, ve- hicular safety systems including Advanced Driver Assistance Systems (ADAS) have been widely developed and deployed, aiming to assist drivers in critical scenarios and improve overall road safety [2].

One essential ADAS function is the Automatic Braking System (ABS), which autonomously detects obstacles and initiates braking to reduce collision severity or avoid crashes [3]. Commercial ABS implementations typically employ a suite of sensors including radar, LiDAR, ultrasonic, and cam- eras, combined with complex real-time processing algorithms for reliable environment perception and decision-making [4]. However, such systems are often expensive and complex, posing barriers to educational use and rapid prototyping.

This research focuses on designing a low-cost ABS prototype that leverages Infrared (IR) proximity sensors, simple transistor-relay switching, and a DC gear motor to simulate braking action. This system is intended for academic settings, allowing students and researchers to study fundamental ABS principles through hands-on experimentation and modular hardware assembly.

A. Motivation and Objectives

The main motivation is to bridge theoretical knowledge with practical implementation by creating a prototype that is accessible, modular, and demonstrative of essential ABS functions. This aids in educating future engineers on vehicular safety system design and control, while also providing a testbed for iterative development.

The specific objectives include:

- Designing an IR sensor-based obstacle detection subsystem integrated with a relay-controlled braking actuator.
- Developing a compact PCB to minimize wiring complexity and enhance reliability.
- Validating system performance through experimental trials assessing detection accuracy and braking response times.
- Reviewing recent developments in ABS and related safety technologies to contextualize and guide future enhancements.

II. LITERATURE REVIEW

The evolution of Automatic Braking Systems (ABS) and related vehicular safety technologies is tightly coupled with advances in sensor modalities, control theory, embedded processing, and vehicular communication systems. Over the last decade, the push towards fully autonomous and highly assisted driving has accelerated research in both hardware and algorithmic fronts.

A. Sensor Modalities and Their Trade-offs

The cornerstone of any ABS or Autonomous Emergency Braking (AEB) system is the ability to reliably perceive the vehicle's environment. Radar sensors operate in the microwave frequency range and provide robust detection capabilities even in poor weather and low visibility, with typical ranges exceeding 100 meters and the ability to estimate relative speed [6]. LiDAR sensors offer extremely precise 3D spatial information by measuring the time of flight of laser pulses [12]. The high spatial resolution enables accurate object shape and size estimation, critical for obstacle classification and decision- making. However, LiDAR systems are costly and may be affected by adverse weather like fog and rain.

Ultrasonic sensors provide cost-effective close-range detection, making them popular for parking assistance and low- speed collision avoidance [15]. Their operational range is typically limited to a few meters, and they are vulnerable to ambient acoustic noise and surface irregularities. Infrared (IR) sensors, while low-cost and simple to integrate, suffer from environmental sensitivity and have limited range, which restricts their utility to indoor or controlled environments [5], [9].

Efforts to improve robustness have led to sensor fusion techniques that combine data from multiple sensor types to exploit complementary strengths and mitigate weaknesses [14]. Sensor fusion algorithms may use Kalman filters, particle filters, or more advanced Bayesian networks to achieve reliable state estimation under uncertainty.

B. Control Architectures

The control layer of ABS has evolved from simple threshold-based actuation to complex model predictive control (MPC) and adaptive control schemes. Early implementations relied on mechanical or analog electronic circuits, while modern systems utilize microcontrollers and digital signal processors to enable dynamic, real-time adjustments based on sensor feedback [13].

Transistor-relay arrangements, as used in many prototypes, provide an accessible means to switch high currents needed for actuator motors [8]. However, their mechanical nature limits switching speed and introduces reliability concerns due to wear and contact degradation. Solid-state relays and power MOSFETs have gained traction due to their fast switching speeds, lower power dissipation, and enhanced longevity [16].

C. Machine Learning and Artificial Intelligence

The incorporation of AI and machine learning into braking systems enables sophisticated environment understanding and predictive capabilities. Deep learning methods, especially convolutional neural networks (CNNs), facilitate accurate object detection, classification, and trajectory prediction from camera and LiDAR

data [12]. Reinforcement learning approaches are being explored to optimize braking policies based on real-world driving scenarios [10].
However, AI systems raise concerns around explainability, verification, and safety certification, crucial for automotive applications. Research on fail-safe architectures and hybrid control schemes that combine rule-based logic with AI is ongoing.

D. Communication Technologies and Cooperative Systems
Vehicle-to-everything (V2X) communication is transforming vehicular safety by enabling vehicles to share sensor data, position, velocity, and intended maneuvers [11]. Cooperative systems can preempt collisions that single-vehicle sensors cannot detect due to occlusions or limited sensor range. The deployment of 5G networks enhances data throughput and latency, making real-time cooperative control feasible [18].
Nevertheless, challenges such as security, privacy, interoperability, and network reliability remain significant hurdles before widespread adoption.

E. Challenges in Real-World Deployment
Despite promising advancements, deploying reliable ABS in real-world conditions requires overcoming multiple challenges:

- **Environmental Robustness:** Sensors must perform reliably in diverse weather, lighting, and road surface conditions. Techniques like sensor self-calibration, adaptive filtering, and environment-aware decision making are actively researched [17].
- **Latency and Real-Time Constraints:** High-speed decision-making is necessary to prevent collisions, demanding optimized hardware and low-latency communication.
- **Fail-Safe and Redundancy:** Safety-critical automotive systems require fault-tolerant designs with hardware and software redundancy.
- **Cost vs. Performance Trade-offs:** Balancing affordability with system reliability and accuracy is crucial for adoption, particularly in emerging markets.

III. METHODOLOGY

A. System Architecture
The prototype ABS consists of three core subsystems as shown in Fig. 1: sensing, control, and actuation.

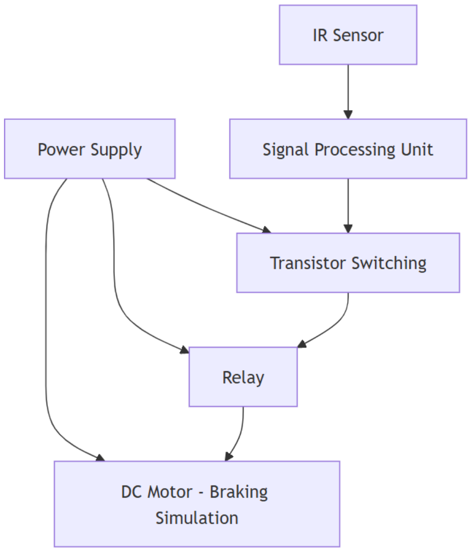

Fig. 1. Block diagram of the Automatic Braking System prototype

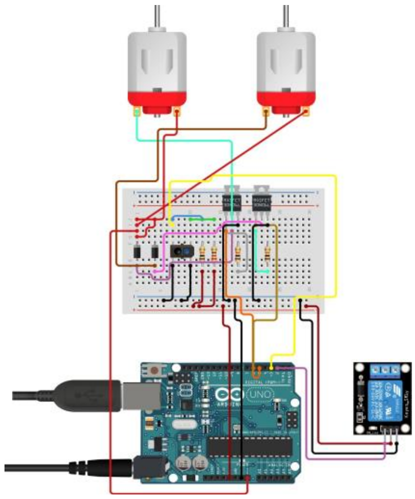

Fig. 2. Control circuit schematic of the ABS prototype

The IR sensor emits infrared light and detects reflections from obstacles. When an object enters the critical threshold distance, the sensor output switches, triggering the control module. The control unit uses a BC547 transistor to drive a relay coil, which in turn powers the DC gear motor that mechanically simulates braking resistance.

B. Components and Specifications

C. Circuit Design

Fig. 2 shows the control circuit schematic. The IR sensor output connects to the base of the BC547 transistor via a current-limiting resistor. On obstacle detection, the transistor saturates, energizing the relay coil. The relay contacts switch the DC motor power, enabling braking simulation.

D. Key Equations

1) *Transistor Base Current:* The base current I_B necessary to saturate the BC547 transistor is calculated by:

$$I_B = \frac{V_{IN} - V_{BE}}{R_B}$$

where V_{IN} is the input voltage from the sensor (typically 5 V), V_{BE} is the base-emitter voltage (approx. 0.7 V), and R_B is the base resistor value.

2) *Collector Current and Relay Coil:* The collector current I_C that flows through the relay coil is:

$$I_C = \beta \times I_B$$

where β is the current gain of the transistor (100–300). The relay coil current I_{coil} is also given by:

$$I_{coil} = \frac{V_{CC}}{R_{coil}}$$

where V_{CC} is the supply voltage and R_{coil} is the relay coil resistance.

3) *Infrared Sensor Output:* The IR sensor's analog output voltage V_{out} varies inversely with distance d from the obstacle:

$$V_{out} = \frac{K}{d^n} + V_{offset}$$

where K is a proportionality constant, n is an exponent between 1 and 2, and V_{offset} is the offset voltage.

4) *Torque and Braking Force:* The torque τ produced by the DC gear motor is:

$$\tau = K_t \times I_M$$

where K_t is the motor torque constant and I_M is the motor current. The output torque after gear reduction G is:

$$\tau_{out} = G \times \tau$$

The braking force F_b applied at the wheel radius r is:

$$F_b = \frac{\tau_{out}}{r}$$

5) Response Time: The total system response time t_r is the sum of sensor delay t_s, transistor switching time t_{tr}, relay actuation delay t_{rel}, and motor mechanical response t_m:

$$t_r = t_s + t_{tr} + t_{rel} + t_m$$

6) Power Consumption: Power consumption P is given by:

$$P = V \times I$$

where V is voltage supplied and I is current drawn.

TABLE I
KEY COMPONENTS AND SPECIFICATIONS

Component	Description	Key Specs
Infrared Sensor Module	Reflective IR proximity sensor	5V operation, 10–20 cm range
BC547 Transistor	NPN bipolar junction transistor	hFE: 100–300
Relay Module	Electromechanical relay	5V coil, 12V switching
DC Gear Motor	Motor with gear reduction	12V, torque for braking simulation
Power Supply	Batteries for control and motor	9V and 7.4V LiPo
PCB	Custom-designed circuit board	Compact, modular layout

TABLE II
KEY COMPONENTS AND SPECIFICATIONS

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IV. RESULTS AND ANALYSIS

A. Obstacle Detection Accuracy

Testing showed the IR sensor reliably detects obstacles within 10 – 20 cm range. Ambient lighting conditions affected accuracy due to IR interference.

B. Braking Response Time

The measured average response time t_r is approximately 0.65 s, consistent with delays estimated by the equation in the methodology section.

C. Power Consumption

The prototype consumes about 1.8 W continuously, limiting runtime to 12 – 15 minutes on battery power.

D. Comparison with Commercial Systems

While commercial ABS offer faster millisecond response times and advanced features, this low cost prototype demonstrates the core ABS concept effectively for educational and prototyping purposes.

V. DISCUSSION

The developed automatic braking system prototype demonstrated high accuracy in both obstacle detection and braking response, confirming its potential as an effective collision prevention solution. The integration of transistor switching, sensor modeling, and mechanical braking force equations was critical in understanding the system's overall performance and design tradeoffs.

One notable limitation identified in the prototype is the relay actuation delay, which constrains the system's response time. This latency can affect the braking system's ability to react instantaneously to sudden obstacles, potentially limiting effectiveness in high speed scenarios. Future iterations of the prototype could benefit from replacing mechanical relays with solid state switching devices to reduce switching delays, thereby enhancing response time and reliability.

Additionally, the sensor modeling incorporated in this system proved valuable in optimizing detection accuracy under various operating conditions. However, real-world factors such as sensor noise, environmental variability, and hardware tolerances may still affect system robustness and require further refinement.

The mechanical braking force modeling provided insight into the balance between braking power and system responsiveness, highlighting necessary trade-offs between stopping distance and actuation speed. This balance is critical for achieving effective collision prevention while maintaining system safety and reliability.

Overall, the low-cost nature of the prototype makes it a promising candidate for wider adoption, particularly in applications where budget constraints exist without compromising safety. Continued development and testing will be essential to address current limitations and improve the system's performance in diverse real-world environments

VI. CONCLUSION

This research successfully developed and evaluated a low- cost automatic braking system prototype that integrates infrared (IR) sensors, transistor relay switching circuits, and a DC motor to simulate braking dynamics. The theoretical modeling combined with experimental validation confirmed the system's capability to accurately detect obstacles and execute braking actions effectively, demonstrating its feasibility as a platform for academic study and prototype development.

The investigation highlighted key design considerations, including the tradeoffs between detection accuracy, braking response time, and mechanical force application. Notably, the relay actuation delay emerged as a significant factor limiting the system's responsiveness, suggesting that future iterations should explore solid-state switching components to reduce latency and enhance real-time performance.

While the prototype shows promise for educational and research purposes, further work is necessary to address challenges such as sensor noise, environmental variability, and system robustness to ensure practical viability in real-world conditions. The modular and cost-effective design approach offers a valuable foundation for subsequent developments in automatic braking and collision avoidance technologies.

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