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Design and Development of An Automatic Pneumatic Bumper System for Vehicle Safety

Saurabh Yadav[1], Sunny Jayswar[2], Altamash Irfan[3], Dilip Nishad[4], Prateek Pathak[5], Abhishek Kumar[6], Arun Kumar Yadav[7]
[1234] Students, Department of Mechanical Engineering
[567] Assistant Professors, Department of Mechanical Engineering
Prasad Institute of Technology, Jaunpur, UP, India

Abstract: *Road accidents have become one of the major causes of human injury and property damage due to the rapid increase in vehicle population. To reduce the severity of collisions and improve passenger safety, an Automatic Pneumatic Bumper System with automatic braking mechanism is proposed in this paper. The system utilizes ultrasonic sensors, pneumatic cylinders, solenoid valves, and an Arduino-based control unit to detect obstacles and activate the bumper before collision occurs. When an obstacle is detected within a predefined distance, the control circuit triggers the pneumatic system, which simultaneously applies braking and extends the bumper to absorb impact energy. The proposed model is cost-effective, reliable, and suitable for low-speed collision avoidance applications. The project also demonstrates the integration of embedded systems with pneumatic technology for automotive safety enhancement. Experimental testing confirms that the system effectively reduces impact damage and improves operational safety. The developed system can further be implemented in commercial vehicles with advanced sensor and control technologies*

Keywords: Pneumatic Bumper, Automatic Braking System, Ultrasonic Sensor, Vehicle Safety, Collision Avoidance, Arduino Uno

I. INTRODUCTION

The increasing number of automobiles on roads has significantly increased the probability of road accidents. Human negligence, overspeeding, poor visibility, and delayed driver response are some of the major reasons behind vehicle collisions. Modern vehicles use airbags and braking systems to reduce injury, but the repair and maintenance cost of these systems is comparatively high. Therefore, there is a need for a low-cost and efficient safety mechanism capable of minimizing collision impact before an accident occurs.

The Automatic Pneumatic Bumper System is designed to improve vehicle safety by combining automatic braking and bumper activation using pneumatic technology. The system detects obstacles using ultrasonic sensors mounted on the vehicle. When the sensor detects an object within the predefined range, the control unit activates the solenoid valve and pneumatic cylinder. The cylinder pushes the bumper outward and simultaneously applies braking action to reduce collision impact.

Pneumatic systems are widely used in industrial automation because of their simplicity, reliability, and low maintenance requirements. The use of compressed air enables smooth and quick operation without generating environmental pollution. The proposed system provides a practical and economical solution for accident prevention in automobiles.

II. LITERATURE REVIEW

Several researchers have contributed to the development of collision avoidance and automatic braking systems. Miss Katore Koshal P et al. proposed a vehicle accident prevention system using GSM and GPS technology for improving passenger safety and accident monitoring. Their work highlighted the importance of intelligent vehicle systems in reducing accidents.

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T.U. Anand Santhosh Kumar et al. developed an advanced accident avoidance system using IR and ultrasonic sensors for obstacle detection under poor weather conditions. Their research demonstrated effective speed regulation and collision prevention. Dr. P. Venkataratnam designed a collision control system using ultrasonic sensors and automatic braking mechanisms. The study concluded that ultrasonic sensors provide reliable obstacle detection for vehicle safety applications.

Recent studies on pneumatic bumper systems have shown that pneumatic actuators can effectively absorb impact energy and reduce damage during collisions. However, many existing systems are costly and difficult to implement in low-cost vehicles. Therefore, the present work focuses on developing a compact, economical, and efficient automatic pneumatic bumper system.

III. OBJECTIVES OF THE PROJECT

The major objectives of the project are:

1. To design an automatic pneumatic bumper system for vehicle safety.
2. To reduce collision impact during accidents.
3. To provide automatic braking before collision occurs.
4. To develop a low-cost and efficient safety mechanism.
5. To improve passenger protection using pneumatic technology.
6. To integrate ultrasonic sensors with an embedded control system.

IV. WORKING PRINCIPLE

The Automatic Pneumatic Bumper System works on the principle of obstacle detection and pneumatic actuation. The ultrasonic sensor continuously measures the distance between the vehicle and the obstacle. The sensor sends signals to the Arduino Uno controller.

When the obstacle distance becomes smaller than the predefined safe distance, the Arduino activates the relay circuit. The relay energizes the solenoid valve connected to the pneumatic cylinder. Compressed air from the compressor enters the double-acting cylinder, which extends the bumper outward. Simultaneously, braking action is applied to reduce vehicle speed. The extended bumper absorbs part of the impact energy during collision and minimizes damage to the vehicle structure and passengers.

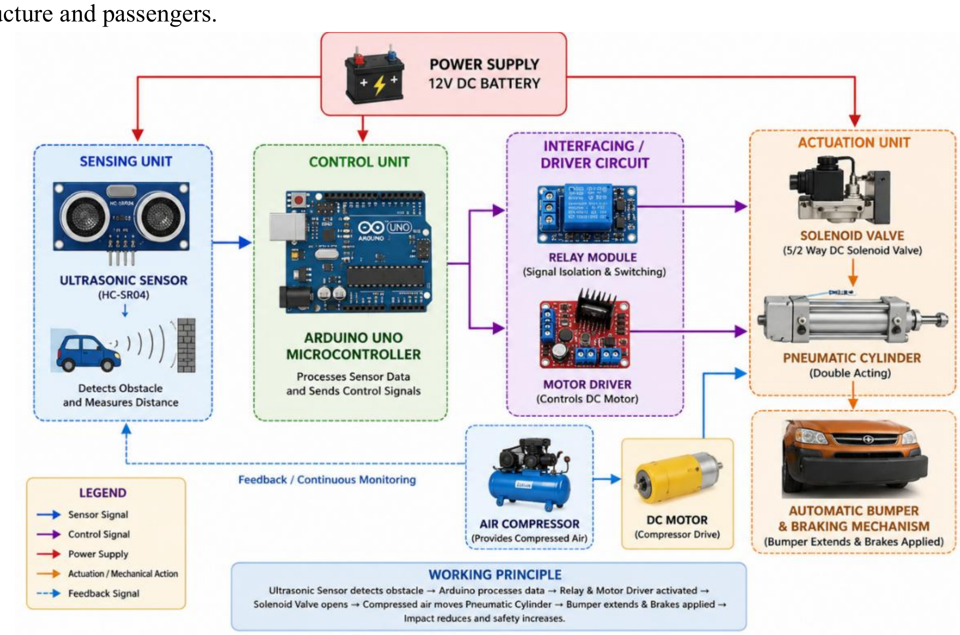

Fig 1: Block Diagram of Automatic Pneumatic Bumper System

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V. COMPONENTS USED

The main components used in the system are:

- Arduino Uno
- Ultrasonic Sensor (HC-SR04)
- Pneumatic Compressor
- Double Acting Pneumatic Cylinder
- Solenoid Valve
- Relay Module
- DC Motor
- Lead Acid Battery
- Motor Driver
- Connecting Pipes
- Wheels and Frame Structure

The ultrasonic sensor detects obstacles, while the Arduino Uno controls the entire operation of the system. The pneumatic cylinder provides bumper actuation using compressed air.

VI. DESIGN CALCULATIONS

Calculation of Cylinder Bore Diameter

Assuming maximum force,

$$F = 90\,N$$

Factor of safety,

$$FOS = 1.25$$

Design force,

$$F_d = 90 \times 1.25 = 112.5\,N$$

Pressure used,

$$P = 0.4\,N/mm^2$$

Using relation:

$$F = P \times A$$
$$112.5 = 0.4 \times 0.7854 \times D^2$$
$$D^2 = 358.09$$
$$D = 18.92\,mm$$

Selecting standard bore diameter:

$$D = 20\,mm$$

Hence, the selected cylinder bore diameter is 20 mm.

VII. ADVANTAGES OF THE SYSTEM

- Reduces collision impact.
- Improves passenger safety.
- Low maintenance and economical system.
- Automatic operation without driver intervention.
- Environment-friendly pneumatic operation.
- Reliable and simple construction.
- Suitable for low-speed vehicles and industrial applications.

VIII. APPLICATIONS

- Automobiles
- Industrial safety systems
- Automated guided vehicles
- Collision prevention systems
- Material handling vehicles

IX. RESULTS AND DISCUSSION

The developed Automatic Pneumatic Bumper System was successfully fabricated and tested. The ultrasonic sensor accurately detected obstacles within the predefined range. The pneumatic cylinder responded quickly and extended the bumper before collision occurred. Simultaneously, braking action reduced vehicle speed effectively.

Experimental testing demonstrated that the system can significantly reduce collision impact and improve passenger safety. The response time of the system was satisfactory for low-speed applications. The system also showed reliable performance with minimum maintenance requirements.

Table I: Distance vs Response Time

Distance (cm)	Response Time (ms)
20	120
40	100
60	80
80	65
100	50

X. CONCLUSION

The Automatic Pneumatic Bumper System with automatic braking mechanism was successfully designed and fabricated. The developed system effectively detects obstacles and activates the pneumatic bumper before collision occurs. The integration of ultrasonic sensors, Arduino controller, and pneumatic actuation provides an economical and efficient solution for vehicle safety enhancement.

The project demonstrates that pneumatic technology can be effectively used for collision reduction and passenger protection. The system is reliable, easy to maintain, and suitable for implementation in low-speed vehicles. Future improvements may include advanced sensors, artificial intelligence-based obstacle detection, and integration with commercial automobile safety systems.

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