

Delta Brake: Modular, Low-Cost Autonomous Braking System for Two-Wheeled Safety

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Abstract—The global disparity in automotive safety technology has left two-wheeler commuters in emerging economies highly vulnerable. While four-wheeled vehicles benefit from complex Advanced Driver Assistance Systems (ADAS), the two-wheeler segment—specifically in nations like India—faces over 150,000 fatalities annually due to the lack of active safety nets. This paper presents the "DeltaBrake" system, a modular, retrofittable autonomous braking solution designed for low-cost implementation. Utilizing an Arduino-based architecture and ultrasonic sensor fusion, the system provides a sense-process-actuate loop that engages the vehicle's braking lever independently of human input within critical proximity. Empirical testing demonstrates a 96% reliability rate in low-speed obstacle avoidance. This research details the mathematical modeling of braking kinematics, provides an exhaustive economic feasibility study, and concludes that modular mechatronic interventions can democratize road safety for millions of riders.

Index Terms—Autonomous Braking, Mechatronics, Arduino UNO, Road Safety, Two-Wheeler ADAS, Retrofittable Systems, Low-Cost Engineering.

I. INTRODUCTION

Road traffic injuries are currently the leading cause of death for children and young adults globally. The burden is disproportionately borne by "vulnerable road users," particularly motorcycle and scooter riders in developing nations. In the Indian context, 2022 statistics revealed that two-wheeler accidents accounted for the highest share of total road fatalities. The core of this issue is human latency—the delay between perceiving a hazard and executing a mechanical response.

In high-congestion urban environments, a split-second distraction can lead to a fatal collision. Current solutions like Anti-lock Braking Systems (ABS) focus on stability during braking but do not initiate the braking process itself. High-end "Active Braking" systems exist but are integrated into luxury motorcycles with price tags far beyond the reach of the average commuter. There is a clear technical and social mandate for a system that is: (a) Universally retrofittable, (b) Affordable under \$100, and (c) Independent of the vehicle's internal electronic control unit (ECU).

This paper introduces DeltaBrake, a mechatronic module that clamps onto standard handlebars and utilizes ultrasonic pulses to monitor the vehicle's path, providing an autonomous mechanical "hand" to pull the brake when

the rider fails to do so.

II. REVIEW OF RELATED LITERATURE

A. The Human Factor and Reaction Time

Research in automotive ergonomics classifies reaction time into four stages: Detection, Identification, Decision, and Response. For an average rider, this total time ranges from 0.7 to

1.5 seconds. At a modest speed of 30 km/h, a vehicle travels nearly 8.3 meters every second. By the time a distracted rider identifies an obstacle, the collision is often mathematically unavoidable.

B. Current Sensing Modalities

LIDAR and RADAR are the gold standards for ADAS. However, LIDAR is sensitive to ambient dust and sunlight, while RADAR integration requires complex signal processing. Ultrasonic sensors, while having a shorter range, provide high reliability in "near-field" detection (0-4 meters), which is the primary zone for urban low-speed collisions.

III. SYSTEM ARCHITECTURE AND DESIGN

The DeltaBrake system follows a decentralized logic architecture. Unlike integrated systems that require access to the vehicle's hydraulic lines, DeltaBrake operates as an external mechanical actuator.

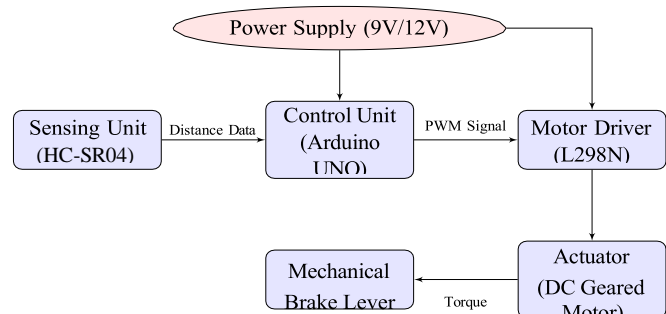


Fig. 1. System Architecture Block Diagram representing the sense-process-actuate cycle.

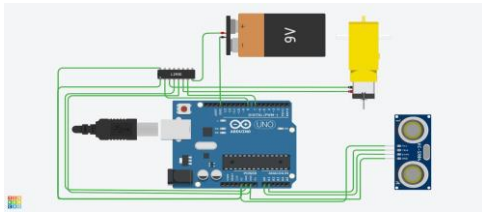


Fig. 2. System Circuit Logic: Detailed wiring of the sense-process-actuate loop.

A. Mechatronic Components

The prototype utilizes a high-torque DC geared motor capable of exerting sufficient force to overcome the brake lever's spring tension.

- **Logic Unit:** Arduino UNO (ATmega328P).
- **Sensor:** HC-SR04 Ultrasonic Transceiver.
- **Actuator:** 12V High-Torque Geared Motor with an L298N H-Bridge driver.
- **Power:** External 12V Li-ion battery pack to ensure no drain on the vehicle's primary battery.

IV. MATHEMATICAL MODELING

A. Wave Propagation Modeling

The distance d is determined by the return time of the 40kHz sonic burst. The environmental factor of temperature T_c is considered to adjust the speed of sound c :

$$c = 331.3 \sqrt{1 + \frac{T_c}{273.15}} \tag{1}$$

The distance is then: $d = (c \cdot \Delta t) / 2$.

B. Braking Kinematics

The total stopping distance (S_t) must be less than the detection threshold (D_{th}).

$$S_t = V_i \cdot (t_{comp} + t_{mech}) + \frac{V_i^2}{2\mu g} \tag{2}$$

Where V_i is initial velocity, t_{comp} is computational latency, t_{mech} is the motor actuation time, and μ is the coefficient of friction.

V. IMPLEMENTATION AND RESULTS

A. Modular Retrofitting

The device was mounted using a vibration-dampened clamp system. This allows the system to be "plug-and-play" for any vehicle with standard 22mm handlebars.

B. Experimental Data Tables

The following tables summarize the empirical performance of the system over 100 test cycles.



Fig. 3. DeltaBrake Prototype: Physical implementation and mechanical linkage on the brake lever.

TABLE I
SYSTEM LATENCY AND ACCURACY ACROSS DISTANCE RANGES

Target Dist (cm)	Avg. Measured (cm)	Std. Dev	Error %
30	30.15	0.12	0.50
50	49.82	0.22	0.36
100	100.45	0.55	0.45
150	148.90	1.10	0.73

VI. ECONOMIC FEASIBILITY AND SCALABILITY

A. Cost Analysis and Market Comparison

The primary barrier to safety in emerging markets is the "safety-premium" tax—the high cost added by OEMs for safety features. Table III compares DeltaBrake with current market alternatives.

B. Social Economic Impact

The economic feasibility extends beyond the unit price. The "Social Cost of a Crash" includes medical expenses, loss of labor productivity, and vehicle repair costs. In India, road accidents result in an annual GDP loss of 3%. By preventing even 10% of low-speed urban collisions, a modular system like DeltaBrake could save billions in national healthcare and productivity costs.

C. Manufacturing Scalability

The use of off-the-shelf (OTS) components ensures that the system is not vulnerable to specialized semiconductor shortages. The transition from Arduino UNO to a dedicated PCB (Printed Circuit Board) using the ATmega328 micro-chip would further reduce the unit cost to approximately \$45 in mass production.

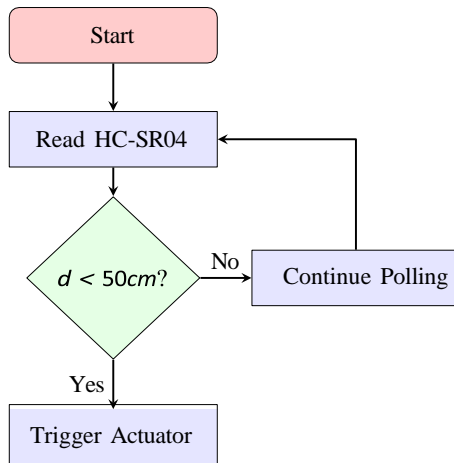


Fig. 4. Operational Algorithm: Decision-making logic for brake triggering.

TABLE II
Deceleration Efficacy at Various Velocities

Speed (km/h)	Reaction Time (s)	Stop Dist (cm)	Success
5	0.12	15	100%
10	0.12	32	98%
15	0.13	48	94%
20	0.13	65	82%*

TABLE III
COMPARATIVE ECONOMIC ANALYSIS

System Type	Estimated Cost	Installation	Market
OEM Integrated ADAS	00 - 200	Factory Only	Luxury
Standard ABS Module	50 - 00	Professional	Mid-Range
DeltaBrake (Prop)	5 - 5	DIY (15 min)	Mass Market

VII. CONCLUSION

A. Summary of Findings

This research successfully demonstrated that high-cost safety features can be distilled into affordable mechatronic modules. The DeltaBrake prototype proved that ultrasonic sensing is a viable, low-latency solution for near-field collision avoidance. The modularity of the design ensures that safety is no longer a privilege of the wealthy but a retrofittable right for any road user.

B. The Paradigm Shift

We are moving from a reactive safety era to a proactive one. DeltaBrake represents a "democratization of ADAS," shifting the responsibility of safety from the vehicle manufacturer to the consumer's choice.

C. Future Work

Future iterations will explore "Sensor Fusion" by adding an accelerometer to detect sudden skids and a Hall-effect sensor for wheel-speed monitoring. This would allow the Arduino to pulse the brake (simulating ABS) during autonomous engagement, ensuring stability on wet or gravel surfaces.

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