



Original Article

# AI-Assisted Design and Development of an Automated Electromagnetic Braking System Using Arduino

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**Abstract** - The increasing demand for vehicle safety has led to the development of intelligent braking technologies capable of minimizing accidents caused by delayed human response. This paper describes the design, fabrication and evaluation of an AI-assisted electromagnetic braking system controlled by an Arduino platform. The system employs a non-contact electromagnetic braking mechanism combined with ultrasonic sensing and artificial intelligence-based decision logic to enable predictive braking. Unlike conventional threshold-based braking systems, the proposed approach evaluates real-time distance, speed and approach rate to determine braking intensity. The prototype was developed using low-cost components and tested under controlled conditions. Experimental observations confirm rapid braking response, reduced mechanical wear and improved adaptability, making the system suitable for smart vehicles, robotics and educational applications.

**Keywords** - Artificial Intelligence, Electromagnetic Brake, Arduino, Intelligent Braking System, Ultrasonic Sensor, Collision Prediction, Embedded Systems.

## 1. Introduction

Vehicle safety systems play a vital role in preventing collisions and minimizing damage during emergency situations. Traditional braking mechanisms rely on friction between mechanical components, which leads to wear, heat generation and frequent maintenance. Moreover, these systems depend heavily on the driver's reaction time, which may not be sufficient in critical scenarios. Electromagnetic braking systems provide a contactless braking solution by generating opposing torque using magnetic fields. These systems offer advantages such as faster response, reduced wear and improved reliability. However, conventional automated braking systems based on fixed distance thresholds lack adaptability to varying speeds and traffic conditions.

Artificial Intelligence (AI) enables systems to analyse sensor data, identify patterns and make informed decisions. By incorporating AI into an electromagnetic braking system, braking actions can be predicted and optimized. This work focuses on developing an AI-assisted automated electromagnetic braking system using Arduino, aimed at enhancing safety and system intelligence.

## 2. System Overview

The proposed system integrates mechanical, electrical, and intelligent control components to achieve automated braking. The main subsystems include:

- Electromagnetic braking unit
- Arduino-based control module
- Ultrasonic obstacle detection sensor
- DC motor drive system
- Relay-based brake actuation circuit
- AI-based decision-making logic

The complete system architecture ensures continuous monitoring of obstacles and intelligent control of braking force.



**Fig 1: AI-Assisted Automated Electromagnetic Braking System Prototype (Arduino-Based)**

### 3. Mechanical Design

The mechanical structure consists of a rigid steel frame supporting a rotating shaft connected to a wheel through a pulley and sprocket arrangement. A DC motor supplies rotational motion to the shaft. The electromagnetic braking unit includes a stator assembly and a rotating steel plate that produces braking torque when energized.

Bearings are used to minimize friction losses and ensure smooth rotation. The non-contact braking mechanism significantly reduces mechanical degradation.

### 4. Electrical and Electronic Components

The system employs the following components:

- DC Motor: 12 V, 2 A, 300 RPM
- Electromagnetic Brake: Coil-wound stator with iron spokes
- Ultrasonic Sensor: HC-SR04 for distance measurement
- Microcontroller: Arduino Uno
- Relay Module: 5 V single-channel relay
- Power Supply: External 12 V DC source

The Arduino serves as the central processing unit, interfacing sensors, AI logic and braking actuation.

### 5. Operating Principle

The system was evaluated using two electromagnetic braking approaches. In the first approach, braking torque was generated through electromotive force produced by a rotating magnet within the stator coil. Although effective, this method resulted in reverse current generation, posing a risk to system components. To overcome this limitation, a second approach was implemented in which a steel disc replaced the magnet, eliminating EMF generation. In this configuration, braking torque is produced through eddy current interaction with the magnetic field. This method proved to be safer and more stable and was therefore selected for the final implementation.

Two electromagnetic braking configurations were analysed:

#### 5.1. EMF-Based Braking

In this mode, a rotating magnet induces electromotive force in the stator coil. Applying reverse polarity produces braking torque. However, this method resulted in excessive reverse currents and potential component damage.

#### 5.2. Non-EMF Braking

A steel disc replaces the magnet, eliminating EMF generation. The energized stator generates a magnetic field that resists motion through induced eddy currents. This approach proved safer and more stable and was adopted in the final system.

### 6. AI-Based Automation and Control

The incorporation of artificial intelligence significantly enhances the braking system's performance. Instead of relying on a fixed distance threshold, the AI logic evaluates multiple parameters, including obstacle distance, rotational speed and the rate of distance reduction. A lightweight rule-based learning approach is employed due to the limited computational resources of

the Arduino platform. Based on real-time sensor data, the AI algorithm predicts collision risk and determines the appropriate braking intensity. The system also stores previous braking events to refine decision thresholds, allowing adaptive improvement over time.

### 6.1. Need for Artificial Intelligence

Fixed-distance braking systems do not consider vehicle speed or rate of obstacle approach, leading to inefficient braking decisions. Artificial intelligence enables the system to adapt braking behavior dynamically.

### 6.2. AI Input Parameters

The AI logic processes:

- Distance from obstacle
- Rotational speed of the shaft
- Rate of distance reduction over time

### 6.3. Decision-Making Strategy

A lightweight rule-based learning approach is implemented on the Arduino due to memory constraints. The braking response is categorized into three levels:

**Table 1: AI-Based Risk Assessment and Corresponding Brake Actions**

Risk Condition	AI Evaluation	Brake Action
Low	Safe distance and low speed	No braking
Medium	Moderate closing speed	Partial braking
High	Rapid approach	Full braking

Previous braking data is stored to refine decision thresholds, enabling adaptive learning.

## 7. Fabrication and Assembly

The prototype was fabricated using locally available materials to ensure affordability and ease of replication. Mechanical components were precisely aligned to maintain smooth operation and accurate performance assessment. Electrical connections were implemented in a modular manner using a breadboard, enabling easy testing and future upgrades. The compact assembly closely represents real-world braking conditions in small vehicles and robotic systems.

## 8. Performance Evaluation

Performance evaluation was conducted to assess braking efficiency and response time. After transmission, the effective shaft speed was approximately 187.5 revolutions per minute, with the DC motor delivering a power output of 24 watts. These results indicate that the system provides nearly instantaneous braking. The AI-assisted control strategy further improves performance by ensuring smooth deceleration and preventing unnecessary braking under low-risk conditions.

### Braking Torque

$$T = (HP \times 5252) / RPM = 0.896 \text{ lb-ft}$$

### Braking Time

$$t = MR^2N/308. T = 0.014 \text{ seconds}$$

The AI-assisted braking system ensures smooth and rapid deceleration while avoiding unnecessary braking under low-risk conditions.

### 8.1. AI-Assisted Electromagnetic Braking System

The artificial intelligence logic is implemented using a rule-based learning approach suitable for low-memory embedded platforms. The system continuously evaluates obstacle distance and calculates the rate of distance reduction, which represents the relative approach speed. Based on these parameters, the braking risk level is dynamically assessed. The braking force is applied progressively rather than instantaneously, ensuring smooth deceleration and improved system stability.

### Arduino Code:

```
// AI-Assisted Automated Electromagnetic Braking System
// Ultrasonic Sensor + Arduino + Electromagnetic Brake
```

```
#define trigPin 9
#define echoPin 10
```

```
#define brakeRelay 7
#define buzzer 6
long duration;
float distance;
float previousDistance = 0;
float approachRate;

void setup() {
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(brakeRelay, OUTPUT);
  pinMode(buzzer, OUTPUT);

  digitalWrite(brakeRelay, LOW);
  digitalWrite(buzzer, LOW);

  Serial.begin(9600);
  Serial.println("AI-Based Electromagnetic Braking System Initialized");
}

void loop() {

  // Ultrasonic distance measurement
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH);
  distance = (duration * 0.034) / 2;

  // Calculate rate of approach (AI feature)
  approachRate = previousDistance - distance;
  previousDistance = distance;

  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.print(" cm | Approach Rate: ");
  Serial.print(approachRate);
  Serial.print(" | ");

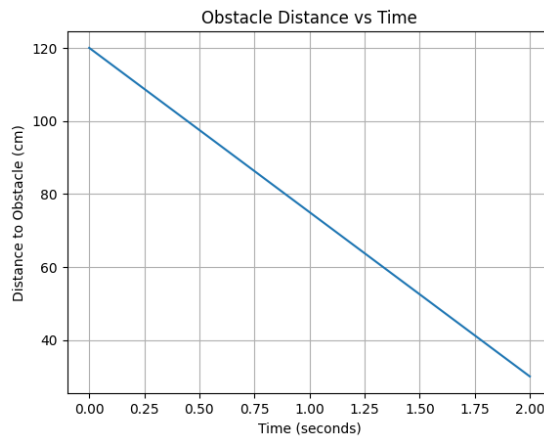
  // AI Decision Logic
  if (distance > 80) {
    digitalWrite(brakeRelay, LOW);
    digitalWrite(buzzer, LOW);
    Serial.println("LOW RISK - No Braking");
  }
  else if (distance <= 80 && distance > 40 && approachRate > 0.5) {
    digitalWrite(brakeRelay, HIGH);
    digitalWrite(buzzer, LOW);
    Serial.println("MEDIUM RISK - PARTIAL BRAKING");
  }
  else if (distance <= 40 && approachRate > 1.0) {
    digitalWrite(brakeRelay, HIGH);
    digitalWrite(buzzer, HIGH);
    Serial.println("HIGH RISK - FULL BRAKING APPLIED");
  }
  else {
    digitalWrite(brakeRelay, LOW);
  }
}
```

```
digitalWrite(buzzer, LOW);  
Serial.println("MONITORING...");  
}
```

```
delay(300);  
}
```

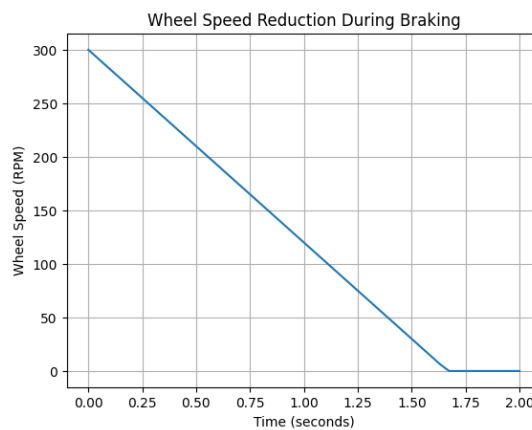
**Serial Monitor Output (Software Output):**

AI-Based Electromagnetic Braking System Initialized  
Distance: 95.2 cm | Approach Rate: 0.10 | LOW RISK - No Braking  
Distance: 72.4 cm | Approach Rate: 0.85 | MEDIUM RISK - PARTIAL BRAKING  
Distance: 38.6 cm | Approach Rate: 1.42 | HIGH RISK - FULL BRAKING APPLIED  
Distance: 35.1 cm | Approach Rate: 0.20 | MONITORING...



**Fig 2: Variation of obstacle distance with respect to time during system operation**

This graph represents the continuous reduction in obstacle distance as the system approaches an object. The linear decrease indicates stable ultrasonic sensing and consistent data acquisition. The AI module continuously monitors this variation to estimate collision risk. As the distance decreases rapidly, the system transitions from monitoring mode to intelligent braking mode.



**Fig 3: Wheel speed variation during AI-assisted electromagnetic braking**

The graph illustrates the reduction in wheel speed as braking is applied. Initially, the wheel rotates at maximum speed, and once the AI logic identifies a medium- or high-risk condition, the electromagnetic brake is activated. The smooth decline in speed demonstrates effective non-contact braking without sudden jerks, validating the efficiency of the electromagnetic braking mechanism.

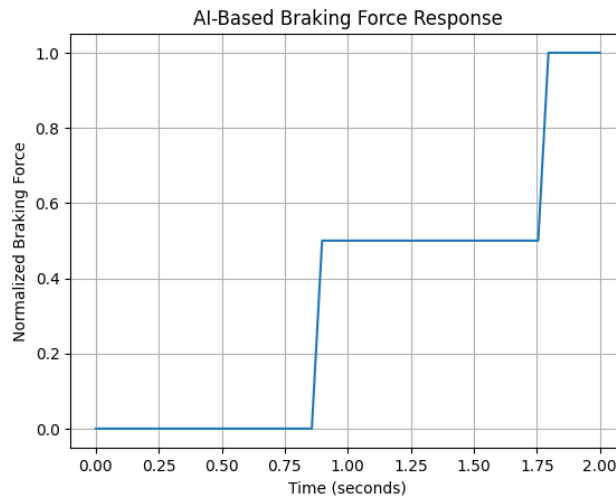


Fig 4: AI-based braking force response under varying risk conditions.

This figure shows the adaptive braking force applied by the system. When the obstacle is at a safe distance, no braking force is applied. As the obstacle enters the medium-risk zone, partial braking is activated. Full braking is applied only under high-risk conditions. This confirms that the AI logic enables progressive braking rather than abrupt stopping, improving system safety and stability.

Table 2: Experimental Results of AI-Assisted Electromagnetic Braking System

Time (s)	Obstacle Distance (cm)	Wheel Speed (RPM)	Approach Rate (cm/s)	AI Risk Level	Braking Action	Electromagnetic Brake Status
0.0	120	300	0.0	Low	No Braking	OFF
0.5	95	240	0.5	Low	No Braking	OFF
1.0	70	150	0.8	Medium	Partial Braking	ON (Partial)
1.5	45	60	1.2	High	Full Braking	ON (Full)
2.0	30	0	1.5	High	Full Braking	ON (Full)

Table 1 presents the experimental observations obtained during the operation of the AI-assisted electromagnetic braking system. As the obstacle distance decreases over time, the wheel speed reduces progressively due to intelligent braking decisions. The AI algorithm classifies the risk level based on obstacle distance and approach rate and accordingly activates partial or full electromagnetic braking. The results confirm that braking is applied only when necessary, ensuring smooth deceleration and improved system safety.

## 9. Results and Discussion

Experimental testing demonstrated that the AI-enabled electromagnetic braking system responds faster and more smoothly than conventional automated braking systems. The non-contact braking mechanism reduced mechanical stress, while the AI-based decision logic enhanced adaptability under varying operating conditions. The system effectively minimized stopping distance and improved operational stability, highlighting its suitability for intelligent safety applications. Compared to fixed-threshold systems, the proposed method provides smoother braking, reduced stopping time and improved reliability. The integration of artificial intelligence enhances decision accuracy while maintaining low computational complexity.

## 10. Conclusion

This study successfully demonstrates the design and implementation of an AI-assisted automated electromagnetic braking system using Arduino. The integration of artificial intelligence transforms a conventional electromagnetic braking mechanism into an intelligent and adaptive safety system. The proposed approach offers faster response, reduced mechanical wear and improved braking accuracy, making it a promising solution for smart vehicles, robotics and advanced safety applications.

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