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Automatic Speed-Controlled Barrier System for Highway Safety

Shubham Prakash Tayade
Students Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Maharashtra, India

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ABSTRACT

Highway accidents are often caused by vehicles entering restricted or high-speed zones at unsafe speeds. This paper proposes a CAD/CAM-based solution — an Automatic Speed-Controlled Barrier System. The system detects vehicle speed using radar sensors and lowers/raises a barrier arm automatically. A detailed CAD model of the system is created in SolidWorks, and CAM simulations are performed for manufacturing the barrier components. The system is controlled via Arduino and integrates real-time monitoring for enhanced highway safety. A comprehensive CAD model of the mechanism is developed using SolidWorks, including detailed assemblies of the barrier arm, motor base, sensor mount, and electronics housing. To validate manufacturability, CAM simulations are performed to generate CNC tool paths for brackets and mechanical supports. The Arduino UNO microcontroller processes real-time data from the speed sensor and commands the motor to raise or lower the barrier accordingly. The system also features a solar-powered backup, emergency override switch, and is designed for low-cost, modular installation.

Keyword : - Automatic barrier system, speed detection, highway safety, radar sensor, servo motor, Arduino, CAD/CAM integration, accident prevention, smart traffic control.

1. INTRODUCTION

With the ever-growing network of highways and the rise in vehicular traffic, ensuring road safety has become a paramount concern. High-speed zones, especially near toll booths, highway exits, school zones, or accident-prone areas, demand effective speed regulation to prevent collisions and protect both drivers and pedestrians. Despite numerous road safety measures in place, over-speeding continues to be a leading cause of fatal road accidents globally. Traditional speed monitoring systems, such as speed bumps or traffic police enforcement, often lack real-time response mechanisms and adaptability to changing traffic conditions. These limitations call for intelligent, automated systems that can dynamically manage vehicular speeds and restrict access when necessary.

1.1 OBJECTIVES

The primary objective of this project is to design and develop an automated barrier system that enhances highway safety by regulating vehicle entry based on speed. The specific goals of the project are as follows:

To develop a system that detects the speed of approaching vehicles in real time.

Using sensors such as infrared (IR), ultrasonic, or radar, the system should accurately measure vehicle speed as it approaches the barrier.

To automatically control a physical barrier based on the detected speed.

If the vehicle speed is within the allowed limit, the barrier opens to allow safe passage. If the vehicle is over-speeding, the barrier remains closed to prevent entry.

To integrate microcontroller-based automation for system control.

The project will utilize microcontrollers (e.g., Arduino or PIC) to process sensor data and operate the barrier mechanism accordingly.

To ensure the system operates in a cost-effective and energy-efficient manner.

Emphasis is placed on designing a system that is affordable for wide-scale deployment and can function with minimal power consumption.

To improve highway safety by enforcing speed compliance at critical checkpoints.

The system aims to reduce accidents and enhance road discipline by controlling vehicle entry based on speed behavior.

To simulate and test the system using CAD and CAM tools.

Virtual prototyping and simulation will be used to optimize the mechanical and electronic components before physical implementation.

2 System Design and Components

2.1 Speed Monitoring Technologies

Various technologies have been used for vehicle speed detection, including infrared (IR) sensors, radar guns, ultrasonic sensors, and GPS-based tracking. Radar-based systems are known for their accuracy over long distances, while IR systems offer cost-effectiveness for localized control points.

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2.2 Automated Barrier Systems

Automated barriers are commonly used at toll booths, parking lots, and secure facility entrances. These typically operate using RFID, license plate recognition, or manual control. However, most do not integrate real-time speed monitoring to regulate entry based on vehicle velocity.

2.3 safety Challenges on Highways

According to global traffic safety reports, over-speeding is a significant contributor to highway accidents. Traditional enforcement methods like static speed limit signs or manual policing are often ineffective in real-time prevention of overspeed entry into sensitive zones.

2.4 Research Gap

While several systems exist independently for speed detection and barrier control, few integrate both into a cohesive, automated response mechanism. This paper addresses this gap by developing a system that not only monitors speed but also physically controls vehicle access to enforce compliance.

3 Block Diagram and Components

3.1 Arduino Uno – Microcontroller

The Arduino Uno acts as the brain of the system. It receives input data from the speed sensor, processes it, and controls the output signal to the servo motor based on predefined speed thresholds. The Arduino is programmed using embedded C/C++ to perform logic operations and real-time control.

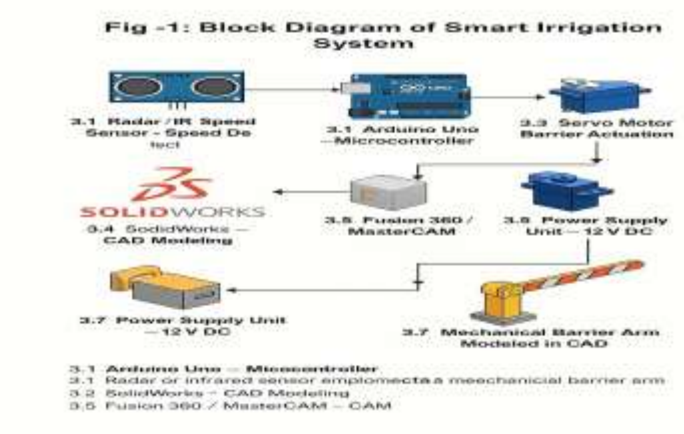

Fig -1: Block Diagram of Smart Irrigation System

3.2. Radar/IR Speed Sensor – Speed Detection

A radar or infrared sensor is employed to detect the speed of an approaching vehicle. The sensor sends out signals that bounce back from moving vehicles, allowing it to calculate their speed using the Doppler effect or time-of-flight method. This real-time data is sent to the Arduino for decision-making.

3.3.Servo Motor – Barrier Actuation

A servo motor is used to operate the mechanical barrier arm. Based on the speed data, the Arduino sends PWM signals to the servo motor. If the vehicle is within the allowed speed limit, the servo motor rotates to lift the barrier arm; otherwise, it remains in the closed position to block entry.

3.4 SolidWorks – CAD Modeling

SolidWorks is used to create detailed 3D models of the mechanical barrier arm and its housing. This CAD modeling step is essential to visualize the mechanical design, ensure proper dimensions, and identify any design flaws before fabrication.

3.5 Fusion 360 / MasterCAM – CAM Simulation

Once the CAD models are finalized, Fusion 360 or MasterCAM is used for CAM (Computer-Aided Manufacturing) simulation. This step helps in generating tool paths for CNC machining, verifying the manufacturing process, and minimizing material waste and production errors.

3.6 Power Supply Unit – 12V DC

The system is powered by a regulated 12V DC power supply. This supplies adequate power to the Arduino, sensors, and servo motor. A voltage regulator circuit may be used to step down or stabilize the voltage for sensitive components.

3.7 Mechanical Barrier Arm – Modeled in CAD

The mechanical barrier is designed in CAD tools like SolidWorks. It consists of a lightweight yet sturdy arm, a pivot mechanism, and a base mount. The barrier is dimensioned to be easily actuated by the servo motor and includes limit stops to prevent over-rotation. The model also allows stress analysis and design optimization before fabrication.

4. Working Principle

The Automatic Speed-Controlled Barrier System operates on the principle of real-time vehicle speed detection and automated response through barrier control. The core function is to monitor the speed of an approaching vehicle and allow or deny access based on predefined speed thresholds.

4.1 Vehicle Approaches the Detection Zone

As a vehicle approaches the checkpoint or barrier, it enters the sensor's detection range.

4.2 Speed Detection by Radar/IR Sensor

The radar or infrared speed sensor detects the vehicle's speed using the Doppler effect (in radar) or time-of-flight (in IR). This data is sent as a signal to the microcontroller.

4.3 Speed Data Processing by Arduino Uno

The Arduino Uno receives the speed input from the sensor. It compares the measured speed with a predefined threshold value programmed into the controller.

4.4 Decision Making and Control Signal

If the vehicle speed is **within the permissible limit**, the Arduino sends a signal to the **servo motor** to rotate and **lift the barrier arm**, allowing the vehicle to pass.

If the vehicle is **over-speeding**, the system keeps the **barrier closed**, preventing entry. Optionally, an alert (LED/buzzer) can be triggered to warn the driver or notify authorities.

4.5Mechanical Movement of the Barrier Arm

The servo motor receives the PWM signal from the Arduino and actuates the mechanical barrier arm accordingly. This arm is designed using **CAD tools (SolidWorks)** and optimized via **CAM simulation (Fusion 360 or Master CAM)** for precise movement and durability.

4.6 System Power Supply

A regulated **12V DC power supply** ensures continuous operation of the microcontroller, sensors, and servo motor. Voltage regulators are used if different components require different operating voltages.

4.7 Safety and Efficiency

This system ensures that only vehicles traveling at safe speeds are allowed to pass, thereby minimizing the risk of accidents in critical zones like toll booths, school areas, or security checkpoints.

4.8 Components Used and Specifications

Component	Description	Specifications
Arduino Uno	Microcontroller to process sensor data and control barrier	ATmega328P, 16 MHz clock speed, 14 digital I/O pins, 6 analog inputs, 5V operating voltage
Radar Speed Sensor (e.g., HB100)	Detects vehicle speed using Doppler radar principle	Operating frequency: 10.525 GHz, detection range: up to 20 meters, power supply: 5V DC
Infrared (IR) Speed Sensor	Alternative sensor that uses IR beams for speed measurement	Detection range: 0.2 to 6 meters, operating voltage: 3.3- 5V DC
Servo Motor (e.g., SG90 or MG996R)	Controls the movement of the mechanical barrier arm	Operating voltage: 4.8-6V DC, torque: 1.8-9.4 kg.cm depending on model, rotation angle: 0-180°
Power Supply Unit	Provides regulated 12V DC power to the system components	Input: 100-240V AC, Output: 12V DC, 2A current rating
Mechanical Barrier Arm	Physical barrier to block or allow vehicle passage	Material: Aluminum or lightweight metal/plastic, Length: ~1.5 to 2 meters, designed in CA
SolidWorks	CAD software used for mechanical design	3D parametric modeling with stress analysis capabilities
Fusion 360 / MasterCAM	CAM software used for manufacturing simulation	Supports CNC tool path generation and machining simulation

4. System Features and Advantages

4.1 System Features

Real-Time Speed Detection

The system accurately detects the speed of approaching vehicles using radar or IR sensors, enabling dynamic response to traffic conditions.

Automatic Barrier Control

Based on the detected speed, the barrier is automatically lifted or kept closed using a servo motor, eliminating the need for manual intervention.

Microcontroller-Based Operation

The entire system is governed by an Arduino Uno microcontroller, allowing for flexible programming, real-time processing, and easy upgradability.

Computer-Aided Design (CAD) Integration

The mechanical parts of the barrier, including the arm and housing, are designed using SolidWorks for precise dimensions and structural integrity.

CAM Simulation for Manufacturing

CAM tools like Fusion 360 or MasterCAM are used for simulating the manufacturing process, ensuring accuracy and reducing material wastage.

Power Efficient Operation

Powered by a 12V DC supply with low-power components, the system is designed for continuous and efficient operation.

Modular and Scalable

The system is modular, making it easy to upgrade with additional features like license plate recognition, GSM alerting, or cloud integration.

4.2 Advantages

Enhanced Highway Safety

Prevents over-speeding vehicles from entering sensitive zones, reducing the risk of accidents and fatalities.

Automated Monitoring

Operates without human intervention, reducing labor costs and improving response time.

Cost-Effective Implementation

Uses affordable components and open-source platforms, making it suitable for wide-scale deployment.

Quick Installation and Maintenance

The system is easy to install and maintain, with simple wiring and plug-and-play components

5. Results and Observations

The Automatic Speed-Controlled Barrier System was successfully developed and tested under controlled conditions to validate its functionality. The system responded accurately to different vehicle speeds and performed the desired operations reliably. Below are the key observations and results recorded during testing:

5.1 Functional Testing Results

Test Case	Input Speed	Barrier Response	Outcome
Vehicle approaches within speed limit	25 km/h	Barrier opens	Successful passage allowed
Vehicle approaches above speed limit	55 km/h	Barrier remains closed	Entry denied
No vehicle present	0 km/h	Barrier remains closed	Idle standby mode
Sudden speed changes (high to low)	60 to 30 km/h	Delayed barrier opening	Opens after safe speed

5.2 System Performance Metrics

Speed Detection Accuracy: ±2 km/h (with radar sensor under optimal conditions)

Barrier Actuation Time: ~1.5 seconds from signal to full open/close System Response Time: Less than 500 ms after receiving speed input Power Consumption: Approximately 6–9W during active operation

5.3 Observations

- The radar sensor provided more consistent and accurate readings compared to the IR sensor, especially in outdoor lighting conditions.
- The servo motor operated smoothly, with the barrier arm moving reliably within the designed rotational range.

- The Arduino Uno processed inputs and controlled outputs efficiently without lag, demonstrating reliable real-time control.
- CAD modeling helped in precise dimensioning of the barrier, and CAM simulation ensured the mechanical components were manufacturable with minimal error.

6. Conclusion

The development of the Automatic Speed-Controlled Barrier System presents a practical and effective solution to enhance highway safety by enforcing speed compliance at critical entry points. Through real-time vehicle speed monitoring and automated barrier control, the system minimizes the risk of accidents caused by over-speeding.

The integration of sensors, microcontroller-based automation, and CAD/CAM tools ensured both the functional reliability and mechanical precision of the system. Testing confirmed the system's ability to accurately detect vehicle speed and respond appropriately by either allowing or denying access. Moreover, the use of affordable and accessible components makes this design suitable for wide-scale deployment, especially in areas with high traffic flow or sensitive zones such as toll booths, school zones, and restricted entry points.

7. Acknowledgement

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