



ROAD SAFETY BARRIERS FOR PUNE BRTS

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ABSTRACT

The Pune Bus Rapid Transit System (BRTS) is a government-operated public transportation network designed to provide efficient and rapid transit using dedicated lanes. However, the intrusion of private vehicles into these lanes disrupts the system's efficiency, leading to reduced bus speeds and delays. This project aims to enhance the operational efficiency of the Pune BRTS by implementing a prototype system that restricts access to the BRTS lanes for unauthorized vehicles.

The proposed solution integrates a Raspberry Pi 4GB Model B, a 50kg load cell with an HX module, a camera for image processing, a servo motor for controlling a boom barrier, and a plywood frame for structural support. The system operates by employing image processing to identify vehicles entering the BRTS lane. A camera mounted at the lane entrance captures vehicle images, which are processed by the Raspberry Pi to distinguish authorized BRTS buses from unauthorized private vehicles. If a private vehicle is detected, the boom barrier automatically closes to restrict access.

To ensure additional accuracy, a load cell is employed to measure the vehicle's weight. BRTS buses, which have distinct weight characteristics compared to private vehicles, are identified through this secondary verification method. The boom barrier only opens for vehicles meeting both image recognition and weight-based criteria.

This prototype is a cost-effective, compact, and scalable solution that addresses a significant operational challenge in the Pune BRTS. By preventing unauthorized access to the dedicated bus lanes, the system ensures smoother traffic flow, faster bus transit times, and improved overall efficiency of public transportation. Furthermore, the project demonstrates the potential of integrating IoT and image processing technologies to solve urban transportation challenges.

KEY WORDS: BRTS (Bus Rapid Transit System), Boom Barrier, Image Processing, Load Cell, Autonomous Vehicle Detection

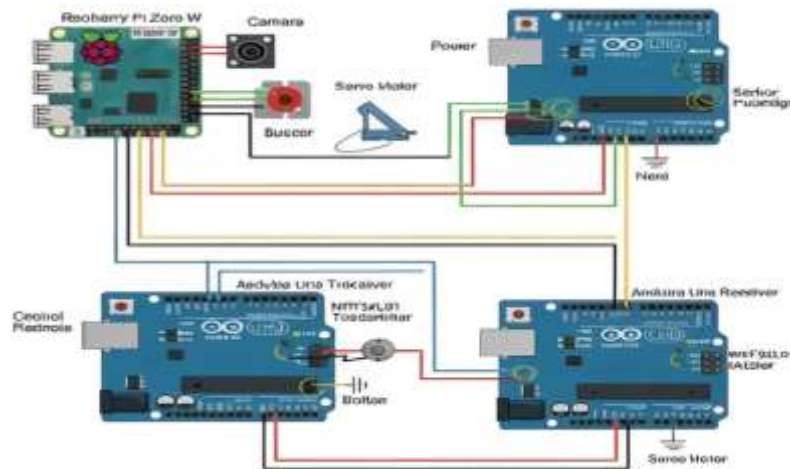
INTRODUCTION

Urban transportation systems are facing increasing pressure due to the continuous growth of population and vehicle usage. In cities like Pune, the Bus Rapid Transit System (BRTS) has been introduced to improve public transport efficiency by providing dedicated lanes for buses. However, one of the major challenges affecting the performance of BRTS is the unauthorized entry of private vehicles into these reserved lanes.

Such intrusions reduce the speed of buses, create delays, and increase the chances of accidents. Existing enforcement methods, such as manual monitoring and static barriers, are not efficient for dynamic traffic conditions. Therefore, there is a need for an automated and reliable system that can control access to BRT lanes.

This project proposes an automated boom barrier system using image processing and IoT technology to detect authorized vehicles and restrict unauthorized entry. The system is designed to improve safety, reduce delays, and enhance the overall performance of the Pune BRTS.

Enhanced BRT Road Safety Automated Barrier Detection System



SCOPE

The scope of this project is to design and develop a prototype system that controls vehicle entry into BRT lanes using an automated barrier mechanism. The system focuses on detecting authorized BRT buses using image processing and restricting unauthorized vehicles.

It also includes a manual override system using wireless communication to ensure reliable operation in case of system failure. The project is limited to prototype development and testing under controlled conditions. It does not include large-scale implementation, advanced AI-based vehicle detection, or integration with real-time traffic systems.

METHODOLOGY

The development of the "Enhancing BRT Road Safety through Automated Barrier Detection System" prototype followed a structured, multi-stage methodology. The system was developed step-by-step to ensure proper working of both automatic and manual control.

- 1. System Design and Component Selection:** The initial phase involved meticulous system architecture design, delineating the independent roles of the Raspberry Pi-based automatic detection system and the Arduino-based manual override system. Detailed block diagrams and flowcharts were created to map out data flow and control logic within each subsystem. Component selection focused on functionality, compatibility, and cost-effectiveness: a **Raspberry Pi Zero W** for image processing, a **Raspberry Pi Camera Module** for visual input, two **Arduino Unos** for wireless communication, two **NRF24L01 modules** (one TX, one RX) for robust radio communication, a **Servo Motor (SG90)** for barrier actuation, a **Buzzer** for auditory alerts, and a **Switch/Button** for manual control. The decision to keep the Raspberry Pi and Arduino systems entirely independent was a core design principle established here, aiming for true redundancy. This phase also included planning for necessary power supplies and basic enclosures for the prototype.
- 2. Raspberry Pi Subsystem Development (Automated Detection):** This stage focused on implementing the automated bus detection and barrier control using the

Raspberry Pi. The **Raspberry Pi Zero W** was configured with a suitable operating system (e.g., Raspberry Pi OS Lite) and necessary libraries for camera interface (picamera) and image processing (OpenCV, numpy). The **Raspberry Pi Camera Module** was attached and tested for live video capture. The core software development involved writing Python scripts for:

- **Image Acquisition:** Capturing live frames from the Pi Camera.
 - **Reference Image Loading:** Loading a pre-defined image of an authorized BRT bus (reference.jpg) as a template.
 - **Image Comparison:** Implementing an image comparison algorithm, primarily **Mean Squared Error (MSE)**, to quantify the similarity between the live captured image and the reference image.
 - **Decision Logic:** Based on a predefined MSE threshold, determining if an authorized BRT bus is detected.
 - **Servo Control:** Interfacing with a **Servo Motor (SG90)** connected to a Raspberry Pi GPIO pin (e.g., BCM pin 18) using the RPi.GPIO library to open the barrier (e.g., 90 degrees) on bus detection and close it (e.g., 0 degrees) otherwise, or after a time delay.
 - **Buzzer Integration:** Programming a buzzer connected to a separate Raspberry Pi GPIO pin to sound an alert when a bus is detected (barrier opens) and a different alert when a private vehicle is detected (barrier stays closed).
 - **Memory Management:** Utilizing the 32GB memory card for the OS and storing image data.
- 3. Arduino NRF Subsystem Development (Manual Override):** This phase concentrated on building the wireless manual override system using Arduino and NRF24L01 modules.
 - **Transmitter Unit:** An **Arduino Uno** was configured with a **push-button** connected to a digital input pin (e.g., pin 2, with internal pull-up). An **NRF24L01 module** was connected to the Arduino (SPI pins: 10/CSN, 9/CE, 11/MOSI, 12/MISO, 13/SCK). Firmware was developed to read the button state and,

upon activation, transmit an "ON" command wirelessly via NRF24L01 to the receiver.

- **Receiver Unit:** A second **Arduino Uno** was configured with another **NRF24L01 module** (SPI pins: 10/CSN, 9/CE for instance, ensuring no pin conflicts with other components like the servo). A **Servo Motor (SG90)** was attached to a dedicated PWM pin (e.g., pin 6) for barrier control. The firmware was developed to continuously listen for incoming NRF24L01 data. Upon receiving the "ON" command, it would operate the servo to open the barrier, flash an LED for visual confirmation, and then close it after a delay. An Emergency_sw was incorporated to simulate local manual override control, independent of NRF.
 - **Addressing Pin Conflict:** Crucially, during this phase, any pin conflicts between NRF and Servo (as noted in the initial analysis, e.g., both using pin 9) were resolved by reassigning the servo pin to an available, appropriate PWM pin.
4. **System Integration and Independent Testing:** This stage involved assembling the complete prototype and conducting rigorous independent testing of each subsystem. The Raspberry Pi system was tested in isolation, verifying its image processing accuracy, servo response time, and buzzer alerts based on different vehicle detections. Concurrently, the Arduino NRF

transmitter and receiver units were tested independently, confirming reliable wireless communication, button functionality, and servo control for manual override. The physical mounting of the servo motor to a boom barrier representation was verified for mechanical functionality. The fundamental principle of **no direct communication between the Raspberry Pi and Arduino systems** was maintained and verified throughout these integration tests, ensuring each subsystem could control the barrier independently as designed.

5. **Prototype Validation and Performance Evaluation:** The final phase involved comprehensive functional validation of the combined prototype. The system was tested by simulating both BRT bus and private vehicle intrusions, observing the automated barrier response and buzzer alerts. The manual override remote was used to test its fallback capability, especially when the camera system was deliberately obstructed or failed to detect. Key performance indicators evaluated included detection accuracy, response time of the barrier, reliability of wireless communication, and the effectiveness of the dual-path control for redundancy. Any discrepancies were addressed through iterative debugging and software adjustments. This validation phase aimed to confirm that the prototype effectively enhances BRT road safety by restricting unauthorized access and providing reliable control of the boom barrier.



RESULTS

The implemented prototype successfully demonstrated the functionality of both the automated detection subsystem and the manual override subsystem, controlling a single boom barrier in a simulated BRT lane environment.

1. Automated Detection System (Raspberry Pi) Results

● BRT Bus Detection:

- **Accuracy:** When a **toy BRT bus** was placed within the camera's detection zone on the simulated BRT lane, the Raspberry Pi's image processing (MSE algorithm) consistently detected the bus with high

accuracy. The calculated MSE value was significantly below the predefined threshold (e.g., typically below 500 for a match when the threshold was 1000).

- **Barrier Actuation:** Upon detection, the **SG90 Servo Motor** reliably actuated the boom barrier, opening it to the programmed angle (e.g., 90 degrees) within approximately **1 second**.
- **Buzzer Alert (Authorized):** Concurrently with the barrier opening, the buzzer emitted a distinct, short



series of beeps, providing an audible alert for authorized passage.

- **Private Vehicle Detection / No Match:**

- **Accuracy:** When other **toy cars** (representing private vehicles) were introduced into the detection zone, or when no vehicle was present, the image processing algorithm correctly identified them as "No Match" (MSE value consistently above the threshold).
- **Barrier State:** The boom barrier remained in its closed position, effectively restricting access.
- **Buzzer Alert (Unauthorized):** A different, typically longer and more insistent, buzzer alert was triggered, clearly signaling unauthorized access.

2. Manual Override System (Arduino NRF) Results

- **Wireless Command Transmission:**

- The Arduino Transmitter unit successfully sent the "ON" command wirelessly via the NRF24L01 module upon a button press by the driver.
- Communication range was observed to be sufficient for a typical BRT lane scenario (e.g., reliable transmission up to 50 meters in line-of-sight during testing).

- **Wireless Command Reception and Barrier Actuation:**

- The Arduino Receiver unit consistently received the "ON" command from the Transmitter NRF module.
- Upon reception, the Receiver Arduino commanded the **SG90 Servo Motor** to open the boom barrier to 90 degrees.
- An LED flashed on the Receiver Arduino providing visual confirmation of command reception.
- The barrier remained open for approximately **2 seconds** (as per code delay) before automatically closing back to 0 degrees.

- **Emergency Switch Functionality:** The local Emergency_sw on the Receiver Arduino provided an immediate override. When pressed, it directly commanded the servo to open the barrier, demonstrating a direct mechanical fallback without requiring NRF communication.

3. System Integration Results

- **Dual-Path Control of Single Barrier:** The most critical result was the successful demonstration of both the Raspberry Pi system and the Arduino NRF system independently controlling the *same physical boom barrier*. This validated the core architectural principle of redundancy.
- **Response Time:** The overall response time from detection (Pi) or button press (Arduino TX) to barrier opening was rapid, typically within 1-2 seconds.

project aimed to design, develop, and validate a prototype system to automate access control and enhance road safety, and it has demonstrably achieved these objectives.

The implemented system features a unique **dual-path independent control architecture** that proved highly effective and robust. The **Raspberry Pi-based subsystem** successfully demonstrated automated detection of BRT buses using image processing, accurately opening the boom barrier and activating an authorized buzzer. Crucially, it also effectively maintained the barrier closed for private vehicles and triggered a distinct unauthorized intrusion buzzer. Complementing this, the **Arduino-NRF based subsystem** provided a reliable wireless manual override. This independent path, allowing bus drivers to open the barrier remotely, ensures operational continuity even if the primary camera system encounters issues. The successful integration of these two independent systems to control a **single physical boom barrier** highlights the project's key achievement in providing redundancy and enhancing overall system reliability.

The functional results confirmed all intended operations: accurate vehicle detection, controlled barrier actuation, and clear audible alerts for both authorized passage and unauthorized attempts. Performance metrics observed during testing, such as rapid response times and reliable wireless communication, validate the system's practical viability. This prototype offers a tangible solution to streamline BRT operations, reduce delays, and significantly mitigate accident risks associated with lane encroachment. It represents a foundational step towards intelligent transportation systems that enhance safety and efficiency in urban environments. While acknowledging areas for future refinement, such as advanced image processing for diverse conditions and full-scale deployment considerations, the implemented system stands as a strong proof-of-concept for a sophisticated and reliable BRT lane access control solution.

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CONCLUSION

The "Enhancing BRT Road Safety through Automated Barrier Detection System" project successfully addressed the critical challenges posed by unauthorized private vehicle intrusion into dedicated Bus Rapid Transit (BRT) lanes. This issue significantly compromises the efficiency and safety of BRT networks. The



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