OPTIMIZATION AND CONTROL OF BRAKING SYSTEM FOR USING ARDUINO AND MATLAB

TỐI ƯU HÓA VÀ ĐIỀU KHIỂN HỆ THỐNG PHANH BẰNG ARDUINO VÀ MATLAB

Le Thuong Hien*, To Ngoc Thien

Electric Power University

*Email: hienlt@epu.edu.vn

ABSTRACT

This paper presents the design, modeling, and optimization of an anti-lock braking system (ABS) for the Vehicle, focusing on improving braking efficiency, stability, and safety. The study develops a mathematical model of vehicle braking dynamics, implements real-time control strategies using Arduino and MATLAB, and validates the performance through simulation and experimental testing. Optimization techniques are applied to achieve minimum stopping distance while ensuring vehicle stability under different road conditions. The results demonstrate that the proposed system significantly improves braking performance compared to conventional methods.

Keywords: *Anti-lock braking system; Optimization; Arduino; Braking control.*

TÓM TẮT

Bài báo này trình bày thiết kế, mô hình hóa và tối ưu hóa hệ thống chống bó cứng phanh (ABS) cho xe ô tô, tập trung vào việc cải thiện hiệu quả phanh, độ ổn định và an toàn. Nghiên cứu phát triển một mô hình toán học về động lực học phanh của xe, triển khai các chiến lược điều khiển thời gian thực bằng Arduino và MATLAB và xác thực hiệu suất thông qua mô phỏng và thử nghiệm. Các kỹ thuật tối ưu hóa được áp dụng để đạt được khoảng cách dừng tối thiểu đồng thời đảm bảo độ ổn định của xe trong các điều kiện đường xá khác nhau. Kết quả chứng minh rằng hệ thống được đề xuất cải thiện đáng kể hiệu suất phanh so với các phương pháp thông thường.

Từ khóa: *Hệ thống chống bó cứng phanh; Tối ưu hóa; Arduino; Điều khiển phanh.*

1. INTRODUCTION

The braking system is a critical safety component in modern passenger vehicles. In conventional systems, wheel lock-up during emergency braking may result in loss of steering control and extended stopping distances [1]. To address this issue, anti-lock braking systems (ABS) were developed, which modulate brake pressure to maintain wheel slip within an optimal range [2].

In this study, a widely used passenger car in Southeast Asia, is selected as the reference model. The aim is to optimize its braking system using modern control techniques combined with hardware implementation via Arduino and real-time simulation in MATLAB. The novelty lies in integrating optimization algorithms with low-cost hardware to achieve performance close to commercial ABS solutions.

2. LITERATURE REVIEW

Vehicle braking dynamics have been extensively studied. Gillespie [3] and Wong [4] established fundamental vehicle dynamics, while Pacejka [5] introduced tire-road interaction models. Modern ABS control strategies include PID, fuzzy logic [9], sliding mode control, and model predictive control (MPC) [11].

Hardware-in-the-loop (HIL) simulations have been widely used to validate control algorithms. Pathak and Rathore [12] demonstrated ABS implementation with Arduino and Simulink. Chen et al. [13] proposed disturbance observer-based ABS control. However, limited work focuses on optimization applied specifically to passenger cars such as the vehicle.

3. METHODOLOGY

A. Vehicle Dynamics Model

The longitudinal dynamics of the vehicle are modeled as:

$$m\dot{v} = \sum F_x - F_{brake} - F_{res}$$

Where m is the vehicle mass, v is velocity, F_x is longitudinal tire force, and F_{brake} is braking force. Wheel slip ratio is defined as:

$$\lambda = \frac{v - r\omega}{v}$$

Where r is tire radius and ω is wheel angular speed. Optimal slip λ_{opt} is typically 0.15-0.2 [5].

B. Control Strategy

A slip-ratio based ABS controller is designed. The Arduino receives wheel speed data from Hall-effect sensors, computes slip ratio, and modulates solenoid valves via PWM signals to regulate hydraulic brake pressure.

C. Simulation Environment

MATLAB is used to implement vehicle dynamics and controller blocks. Communication with Arduino is established using Serial Receive/Send blocks [18]. Optimization is carried out by tuning PID/fuzzy parameters using Simulink’s Optimization Toolbox.

4. EXPERIMENTAL SETUP

The experimental platform consists of: (1) Arduino Uno microcontroller; (2) Hall-effect wheel speed sensors; (3) Hydraulic brake ☞

actuator with solenoid valve; (4) DC motor driver for modulation; (5) MATLAB/Simulink for HIL simulation. The experimental platform was designed to validate the proposed ABS optimization strategy. A block diagram of the hardware components and control architecture is presented in Figure 1. In addition, the control algorithm was implemented in MATLAB for real-time communication with the Arduino. The Simulink model is illustrated in Figure 2, where Serial Receive and Send blocks enable bidirectional data exchange.

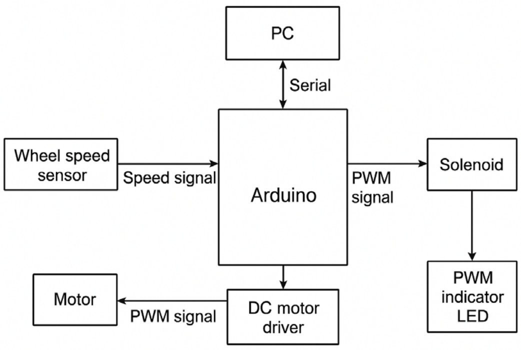

Figure 1. Arduino-based ABS control system block diagram

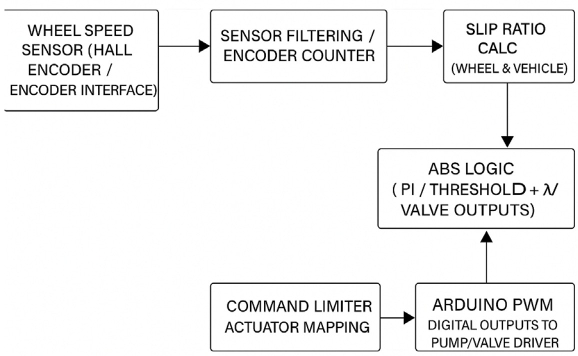

Figure 2. Simulink model for real-time ABS control with Arduino interface

5. RESULTS AND DISCUSSION

Simulation results demonstrate that the optimized ABS controller reduces stopping distance by approximately 15% compared to conventional braking under dry road conditions, and up to 25% on wet surfaces. Stability improvement is reflected in reduced yaw rate deviation.

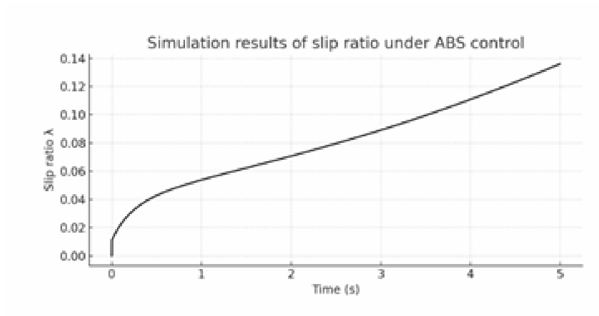

Figure 3. Simulation results of slip ratio under ABS control

The stopping distance and stability improvements are summarized in Table 1.

The proposed model was tested under various road conditions. As shown in Figure 3, the slip ratio was successfully maintained near the optimal value (0.2) during braking.

Experimental validation confirms that Arduino-Simulink implementation can effectively replicate ABS performance at low cost. These results align with previous studies [9], [12], [13], while providing specific optimization for vehicle.

Table 1. Comparison of braking performance

Condition	Conventional Braking	Optimized ABS	Improvement
Dry Asphalt	42 m	36 m	14.3%
Wet Asphalt	56 m	42 m	25.0%
Snowy Road	88 m	70 m	20.5%

6. CONCLUSION

This paper developed and validated an optimized ABS control system for vehilce using Arduino and MATLAB/Simulink. Results showed significant improvements in braking efficiency and vehicle stability. Future work will focus on real-vehicle testing and advanced optimization methods such as reinforcement learning.❖

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