

**SMOOTH DECELERATION CONTROL: A SIMULATION STUDY
BASED ON ADAPTIVE BRAKING FORCE**

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Summary. *This study compares standard PID and time-modulated braking algorithms. While PID provides immediate response, the time-controlled nonlinear modulation delivers smoother deceleration, significantly enhancing braking comfort and control stability in vehicle applications.*

For modern vehicles, the braking system is an indispensable component, playing a crucial role in ensuring safety, enhancing control precision, and improving driving comfort. In this paper, we use a car as the simulation object to explore how adaptive PID control and time-dependent braking force functions can achieve a smooth deceleration process through braking control simulation.

We apply classical Newtonian mechanics as the foundation for simulating the braking process and calculating forces. In an ideal, level plane (ignoring external forces), we define F as the braking force applied to the car, with the goal of controlling deceleration from a given initial speed v_0 and an initial distance S_0 . By doing so, we can record the changes in speed v and the car’s remaining distance to the endpoint S over time. Here, our objective is to design an effective algorithm to control the braking force F , thus realistically simulating the vehicle’s braking behavior.

1. Braking Control Model Based on PID Algorithm.

The PID controller (Proportional-Integral-Derivative) consists of three components: the proportional unit (P), the integral unit (I), and the derivative unit (D). The PID controller compares real-time data with a reference value and uses the resulting difference to compute a new input. This updated input aims to bring the system’s output closer to or maintain it at the reference value. By adjusting the input based on historical data and the rate of change in discrepancies, the PID controller improves the system’s accuracy and stability [1].

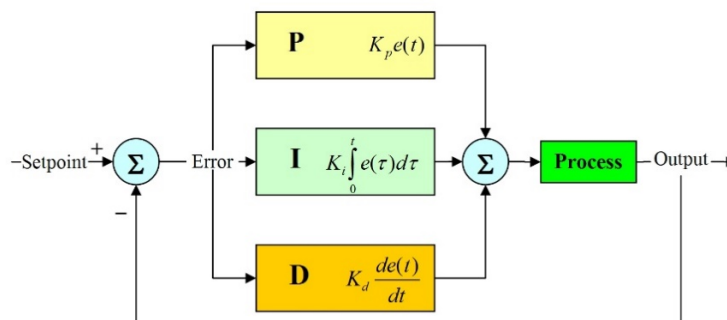


Figure 1 – PID control schematic diagram

Here in figure 1, we define the error as the current distance of the car from the endpoint. By selecting appropriate values for the coefficients K_p , K_i , and K_d , we can control the braking force F at each time step. And then we calculate the car model's acceleration, instantaneous speed, and update the error for the next time step.

2. Time-Modulated Braking Force Control Algorithm.

To achieve proactive and smooth deceleration, the braking force of the car model can be dynamically adjusted using nonlinear time modulation. Nonlinear function $F(t)$ ensures that braking force is more gradual at the beginning and end of the deceleration process, enhancing the overall smoothness of braking. A key feature of this algorithm is its ability to adaptively adjust braking force over different time intervals, resulting in a smoother deceleration experience. This approach is particularly suitable for applications where deceleration comfort is a priority.

3. Simulation results and analysis.

In the condition set with initial velocity $v_0 = 30$, initial distance $S_0 = 180$ and braking start time $t_1 = 1$ s, the braking performance under different models was compared by plotting the velocity and distance versus time curves, as shown in figure 2.

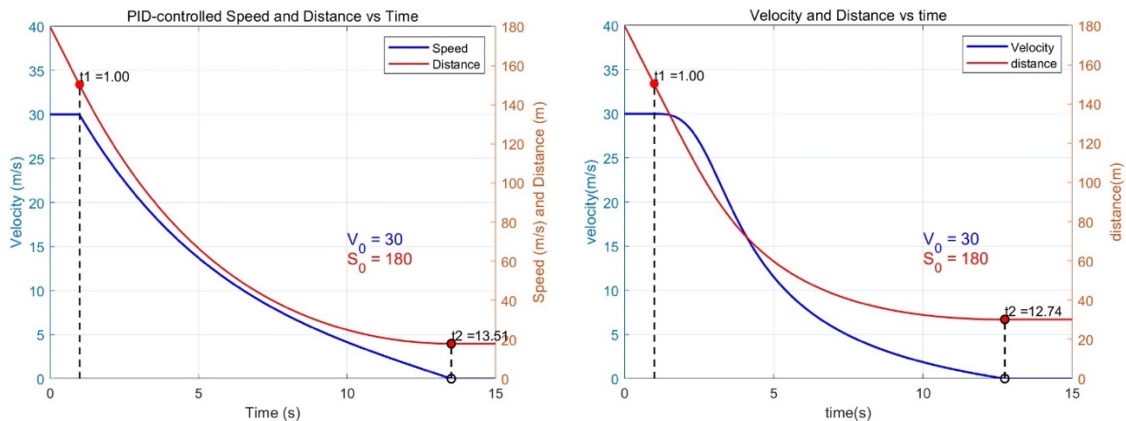


Figure 2 – Comparison of simulation results

Both algorithms achieve the desired braking effect in the model. With the standard PID control, the car's speed responds almost immediately, resembling a sudden brake. In contrast, with the addition of the time-controlled nonlinear modulation algorithm, the speed change becomes noticeably smoother.

References

1. Li Y., Ang K.H., Chong G.C. Patents, software and hardware for PID control: an overview and analysis of the current art[J] // IEEE Control Systems Magazine, 2006. – 26(1). – P. 42–54.