

# The intelligence braking and the pneumatic automatic braking system for autonomous vehicles

## Abstract

Autonomous driving is the main development direction of the automobile in the present and the future. Intelligence braking is the key assembly to realize autonomous driving. The pneumatic brake system is the principle part of commercial vehicle to brake. In order to meet the requirements of autonomous driving, this paper proposed the concept of intelligent braking and pneumatic automatic braking, and then a kind of pneumatic automatic braking circuit is designed. The pressure change rate is used as a new index to evaluate automatic braking and control. This study provides a new theoretical basis for design and application of the pneumatic braking system.

**Keywords:** autonomous driving, intelligence braking, automatic braking, pneumatic braking, pressure change rate

Volume 3 Issue 4 - 2017

**Li Gangyan, Yang Fan**

School of Mechanical and Electronic Engineering, Wuhan University of Technology, China

**Correspondence:** Li Gangyan, School of Mechanical and Electronic Engineering, Wuhan University of Technology, China, Tel +8615271778967, Email gangyanli@whut.edu.cn

**Received:** September 29, 2017 | **Published:** November 14, 2017

## Introduction

Autonomous driving is an important method to solve the missions of a vehicle, which include the safety, health and life.<sup>1</sup> Integration of automotive sensor technology<sup>2,3</sup> and intelligent network technology<sup>4-6</sup> is the core way to develop autonomous driving. During the different development stages from the traditional feature car to the autonomous car, the braking system is always the core assembly to ensure the driving safety and passenger comfort. In recent years, many new brake technologies have been developed to adapt the autonomous driving, such as brake-by-wire,<sup>7-9</sup> wheel-side brake<sup>10</sup> and so on. Nevertheless, all of them were promoted failure for the problem of reliability, this helps to prove that the conventional mechanical brake methods are much more suitable and reliable. However, the conventional brake methods, especially the pneumatic braking system used in commercial vehicles,<sup>11,12</sup> have many defects such as pressure response delay,<sup>13</sup> pressure fluctuation<sup>14</sup> and low control accuracy. These defects make the pneumatic brake system hard to use on autonomous vehicles directly. Thus, to match the development of autonomous vehicles, the concepts of intelligence braking and automatic braking are proposed first, and the function scheme is described simultaneously. Based on the requirement of brake, some structure improvements were adopted on conventional braking system, and then the change rate of pressure is proposed as a new index for evaluation and controlling. In order to adapt the development of autonomous vehicle, these opinions presented here prove a suggestion and reference for designing the braking system of autonomous vehicles.

## Intelligence braking of autonomous vehicles

Intelligence refers to the comprehensive abilities of individual to analyze, judge, act purposefully and effectively interact with the surrounding environment. Toshiyuki Inagaki<sup>15</sup> proposed that the information process of human is consisting of consciousness, condition recognition, behavior selection and behavior execution. Thus, in this paper, the intelligence braking refers to the application of intelligent perception and intelligent communication technology so as to monitor the vehicle motion and road environment state, and then it can take an active brake control technology to drive the brake system to slow down or automatically stop the vehicle, so it helps to avoid or mitigate the collision accident. The intelligent braking is an intelligent

security technology to enhance the stability of vehicle braking and driving safety. As shown in Figure 1, it depicts the structure of the intelligence braking system based on the pneumatic braking system, which is composed of three layers: the perception layer, the decision layer and the executive layer. Among them, the perception layer and the decision layer mainly executive by “V2X inter-vehicle communication and intelligent traffic” and “automatic driving based on intelligent network detection and control”. Thus, the execution layer shown in Figure 1– the pneumatic braking system must have the automatic braking function to adapt the intelligent braking.

## Pneumatic automatic braking of autonomous vehicles

For the vehicle, the intelligence braking system can percept or communicate with surroundings, and then the system takes braking measures independently according to different decision-making. Whereas, for the brake system, it needs to collect the motion data of the vehicle, and then adjust the brake strength automatically according to the threshold determined by the intelligent braking. Consequently, in the braking system level, this automatic intervention called as automatic braking. Its goal is to ensure the stability of the vehicle braking to achieve autonomous driving; the stability threshold is the basis of intervention; the intervention means is the utilization of the dynamic characteristics of brake system, which can adjust the brake pressure distribution dynamically. The working principle of automatic braking is shown in Figure 2.

## Pneumatic braking circuit and its evaluation index for autonomous vehicles

By analyzing Figures 1 & 2, it can be found that both the intelligence braking and automatic braking can brake independently from brake pedal for autonomous vehicles, and then it proposed new requirements for brake system for the lack of or without manual intervention. For the conventional pneumatic braking system, due to the compressibility of the air, the delay of transmission, the nonlinear response characteristics of the components, the pressure deflection caused by leakage and many other factors, all of these reasons make the actual braking deviates from the braking expectations. Therefore, for the autonomous vehicles, the mechanism and regulation of the

brake pressure response characteristics should be understood clearly first, and then the pressure can be controlled accurately through precision control model. On the other hand, a reasonable braking control strategies and control methods should be developed to achieve precision braking. Therefore, it is necessary to find out the aerodynamic characteristics of the basic components, which compose the pneumatic brake circuit, they help to enhance the precision of calculation model, and it is also the basis to enhance the control precision. Furthermore, it is important to improve the conventional brake system to adapt the requirement of automatic brake.

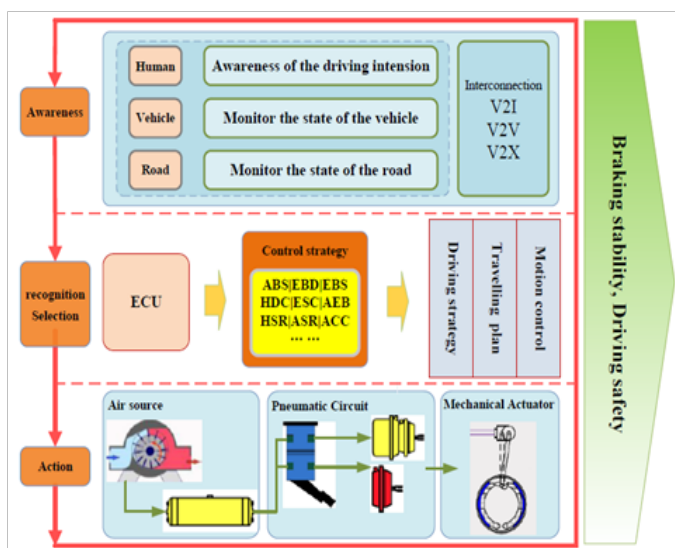


Figure 1 Structure scheme diagram of intelligence braking system.

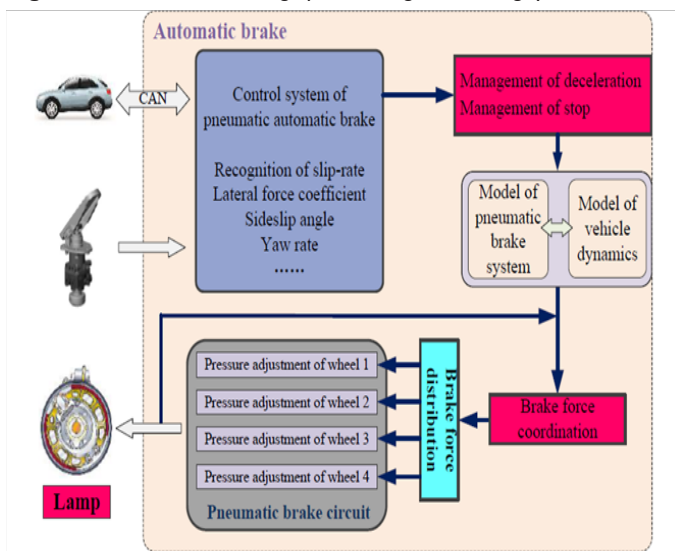


Figure 2 Working principle diagram of automatic braking system.

### Automatic brake circuit for autonomous vehicles

In order to adjust the vehicle motion state dynamically by using the pneumatic braking system, the brake chambers should be supplied with differential pressure according to different braking requirements, and then the braking pressure of each wheel can be controlled independently. Therefore, an automatic pressure regulator (APR) is added in the front of the brake chamber to achieve precise brake

pressure controlling, thereby achieving differential braking to ensure the requirements of braking stability. Finally, to improve the braking ability under emergency conditions and under pressure deflection conditions, and also to ensure the driving safety, a pneumatic booster valve is added before the gas tank. It helps adjust the brake circuit pressure dynamically, and it improves the braking performance under the emergency conditions.

The pneumatics brake circuit used for autonomous vehicles is shown in Figure 3. In which, an APR is added in the circuit compared with the conventional pneumatic brake system, and the pressure can be regulated accurately and independently. For this APR, it should satisfy the following points: the ability to response quickly, the ability to steady the brake pressure, and the ability to regulate the pressure precisely and automatically. In addition, a pneumatic booster valve adds before the tank, the booster valve is parallel combined into the existing system with a diverter valve, and it helps regulate the pressure independently according to the braking requirements and increase the local supply pressure, thereby improving the braking ability and enhancing the system efficiency.

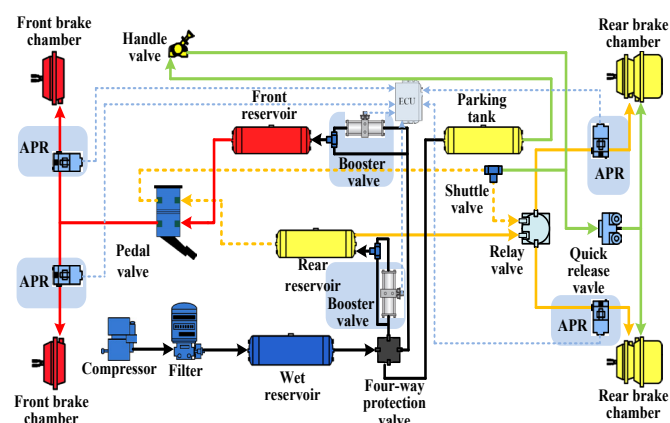


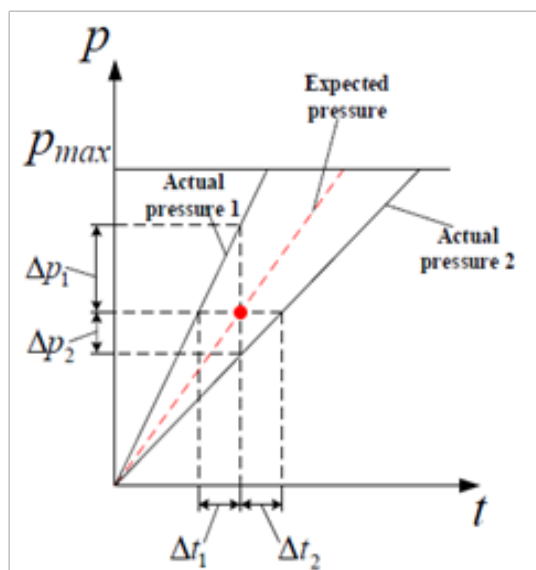
Figure 3 The structure improvement of pneumatic brake circuit.

### The evaluation index of automatic braking circuit—braking pressure change rate

When the vehicle brakes, there is pressure or time deviation between the actual brake pressure response and the expected brake pressure response due to the supply pressure fluctuation and the system transmission delay. These two deviations refer to as brake pressure deviation and brake time deviation; both of them collectively refer to as brake pressure response deviation. A brake pressure–time response of pneumatic braking circuit is simply presented in Figure 4. In the longitudinal axis at the predetermined time ( $\bullet$ ), the actual pressure is less ( $\Delta p_1$ ) or larger ( $\Delta p_2$ ) than the expected braking pressure, this deviation is the brake pressure deviation; In the lateral axis, the braking pressure up to the expectation value is advance ( $\Delta t_1$ ) or hysteresis ( $\Delta t_2$ ), which is the braking time deviation.

For autonomous vehicles, the braking system has the automatic intervention ability, but the manual intervention is weakened, so the brake pressure response must be more accurate. However, as the former has proposed, there may be brake pressure deviation or brake time deviation, and either of them may lead to break failure. Therefore, it must ensure the braking pressure and braking time to meet the braking expectations simultaneously, and then it is necessary to take into account the pressure and time deviation. Here, we propose

to use brake pressure change in unit time, it is defined as the braking pressure change rate, as the evaluation and controlling index for pneumatic automatic braking circuit.



**Figure 4** The relationship of braking pressure-time delay.

Here, the braking pressure change rate is  $\kappa = \frac{\Delta p}{\Delta t}$ . This parameter can eliminate the deviation of braking pressure response process, thereby controlling the braking process more accurately, and then improve the control accuracy.

## Summary

From the perspective of the vehicle, the core of intelligent braking is intelligent perception and intelligent decision-making. In the view of braking system, the core of automatic braking is active braking intervention. For automatic driving vehicles, whether intelligent braking or automatic braking requires the implement layer, the pneumatic brake system, to make improvements in performance. Many facts have proved that the pneumatic system has its superiorities for commercial vehicle in a long time. Therefore, we proposed to identify the basic characteristics of pneumatic components, to design an automatic pressure regulator for pressure control, to adjust the supply pressure independently with a pneumatic booster valve, and use the braking pressure change rate as a control target and other concepts, all of them prove a reference for improving of the brake system of autonomous vehicles.

## Acknowledgments

Li Gangyan research project was partially or fully sponsored by SMC Corporation. In case of no financial assistance for the research work, provide the information regarding the sponsor.

## Conflict of interest

No conflict of interest.

## References

1. Durrant-Whyte, Hugh. A critical review of the state-of-the-art in autonomous land vehicle systems and technology. Sandia National Laboratories. 2001. p. 1–40.
2. Broggi A, Cerri P, Ghidoni S, et al. A new approach to urban pedestrian detection for automatic braking. *IEEE Transactions on Intelligent Transportation Systems*. 2009;10(4):594–605.
3. Kong CY, Gao XB, Nie J, et al. Benefit estimation of automatic braking system based on real-world pedestrian accidents. *Advanced Materials Research*. 2001;889–890:421–424.
4. Chaudhary A, Klette R, Raheja JL, et al. Introduction to the special issue on computer vision in road safety and intelligent traffic. *Eurasip Journal on Image & Video Processing*. 2017;1:16.
5. Dozza M, Idegren M, Andersson T, et al. Platform enabling intelligent safety applications for vulnerable road users. *Iet Intelligent Transport Systems*. 2014;8(4):368–376.
6. Hannan MA, Hussain A, Samad SA. System interface for an integrated intelligent safety system (ISS) for vehicle applications. *Sensors*. 2010;10(2):1141–1153.
7. Cheon JS, Kim J, Jeon J. New brake by wire concept with mechanical backup. *SAE International Journal of Passenger Cars– Mechanical Systems*. 2012;5(4):1194–1198.
8. Glasner ECV, Bergmann H, Marwitz H, et al. Intelligent Braking Management for Commercial Vehicles. *International Mobility Technology Conference and Exhibit*. 2000.
9. Langenwalter J, Kelly B. Virtual design of a 42v brake-by-wire system. *Sae Transactions*. 2003. p. 1–6.
10. Wang Xin, Jiang Jihai. Regenerative braking control strategy for wheel drive hydraulic hybrid vehicle. *Journal of Jilin University (Engineering and Technology ed)*. 2009;39(6):1544–1549.
11. Jurgen Wrede, Heinz Decker. Brake by wire for commercial vehicle. *SAE paper*. 1992.
12. Glasner, ECV, Povel R, Wust K. Electronic Systems Designed to Improve the Active Safety of Commercial Vehicles. *SAE Brasil 98 VII International Mobility Technology Conferences and Exhibit*. 1998.
13. Qin Tao, Li Gangyan, Tu Ming. Bus pneumatic brake circuit delay control and analysis. *Transactions of Beijing Institute of Technology*. 2012;32(5):470–474.
14. Krichel SV, Sawodny O. Non-linear friction modeling and simulation of long pneumatic transmission lines. *Mathematical & Computer Modelling of Dynamical Systems*. 2014;20(1):23–44.
15. WENG Yueh-Hsuan, Dominic Hillenbrand. The Intelligentization of Automobiles Smart-Cars, Robo-Cars and their Safety Governance. *Journal of Science, Technology and Law*. 2014;4:632–655.