Review of PID Control in Industrial Areas for Tobacco Production, Self-driving Car Technology and Robotic Arm Robots

Linxiaoshan Zhang

Xiamen University Malaysia, Jalan Sunsuria,Bandar Sunsuria, 43900 Sepang, Selangor Darul Ehsan, Malaysia

2518487308@qq.com

Abstract. PID control is widely employed across diverse industries such as tobacco production, autonomous car technology, and mechanical arm robotics. This shows that PID control has a substantial developmental potential, so I choose the PID control as the topic. Since few people summarize its different applications in different industries, this study has the motivation to comprehensively summarize the applications of PID. This research provides an in-depth overview and analysis of PID control's varied applications in tobacco production, autonomous car technology, and mechanical arm robotics. It focuses on addressing practical challenges and exploring optimization strategies encountered in these fields. This article is summarized using the methods of the review. PID plays a crucial role in enhancing stability, precision, and response speed in these applications, thereby improving overall control system dynamic response performance. This study consolidated existing literature to offer insights into PID's effectiveness across these industrial sectors, shedding light on its impact and potential for further advancements in control technology.

Keywords: PID control, PID applications, tobacco production, autonomous car technology, mechanical arm robotics.

1. Introduction

PID control is widely utilized in diverse industries such as tobacco production, autonomous car technology, and mechanical arm robotics due to its significance in enhancing operational efficiency and performance. Despite its broad application, there is a lack of comprehensive summaries detailing the specific applications of different PID methodologies across these industries. Current research within these fields focuses on optimizing PID parameters for specific control objectives, such as dynamic response improvement in tobacco production, vehicle stability enhancement in autonomous cars, and precision augmentation in mechanical arm robots. However, there remains a research gap in systematically comparing and synthesizing the various PID applications within each industry. Therefore, this study aims to fill this gap by providing an overview and analysis of the diverse applications of PID control in the fields of tobacco production, autonomous car technology, and mechanical arm robotics. This study employs a review to analyze and explore the significance of PID control across various industries. It aims to assist individuals interested in quickly understanding PID applications by providing

DOI: 10.54254/2755-2721/98/20241094

a structured overview and analysis. This research is valuable for facilitating a clear understanding and systematic review of PID utilization in different sectors, aiding in decision-making processes related to control system design and optimization.

2. Structure and Tuning Methods of the PID Controller

2.1. Structures of the PID Controllers

The common structures of PID controllers are parallel and series types.

In Parallel type, the proportion P, integral I, or derivative D action occurs in separate equation terms and with their combined effect the sum is produced. In this type, each parameter is independent of the other parameters and the corresponding control law is expressed as [1]:

$$u(t) = KC\left(e(t) + \frac{1}{Ti}\int 〚e(t)dt + Td\frac{de(t)}{dt}\right)〛 \tag{1}$$

Series or interactive equation is mainly derived from pneumatic and analog electronic circuit characteristics. Just as an ideal PID equation the change in Kc impacts all the three actions, but both derivatives and integration constants impact on the proportional action [1]. This type has the following control law:

$$e1(t) = e(t) + Td\frac{de(t)}{dt} \tag{2}$$

$$u(t) = Kc\left(e1(t) + \frac{1}{Ti}\int 〚e(t)dt)〛\right. \tag{3}$$

2.2. Tuning Methods

2.2.1. Fuzzy PID Algorithms. Fuzzy set theory was proposed by Professor L.A.Zadeh in 1965, and has made many important research results in various fields [2]. Facing the abovementioned shortcomings of the classic PID control theory in the large-lag control system, the researchers proposed a new control method that combines fuzzy control with traditional PID control algorithms. This control method is first based on the high precision of the classic PID control strategy. Advantages, at the same time adaptive adjustment of the system startup and later PID tuning parameters, and ultimately achieve a good system control effect of the entire adjustment process [2].

2.2.2. Genetic Algorithms (GA). A genetic algorithm is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection. GA can be considered as a multiagent system with distributed strategy where each agent competes to find the best solution to the problem. Then, the GA does not require to communicate information between them. The main algorithm evaluates the cost function for each agent and selects it to participate in the evolution proportionally [3].

2.2.3. Artificial Neural Network Algorithms (ANN). ANN algorithm consists of a multi of layers that represent data architecture, the first layers try to extract from the low-level features and a last layer extract a high-level feature. The artificial intelligence inspired this kind of the architecture that simulates the process, which happen in core sensorial layers in human brain. By applying different scenes, the brain has the ability to automatically extract data representation. The output of this process is classified objects, while the received scene information represents the input. This process simulates the working methodology of the human brain [4].

DOI: 10.54254/2755-2721/98/20241094

3. PID Applications

3.1. PID for Process Control

3.1.1. PID for Tobacco Production. PID optimization is frequently used for tobacco production. It can improve the dynamic response performance of the control system, and scientifically control the temperature and humidity.

Wu et al. proposed a self-tuning fuzzy PID control algorithm for solving the problems of time delay, nonlinear, and time-varying of the drying object that exists in the tobacco cutting and drying process. The experimental results and PID control compared with the stability temperature difference of 0.05 C, the response time difference was 149 seconds, and the overshoot difference was 5.7% [5]. He, Wang and Chen uses the fuzzy PID control strategy to improve the dynamic response performance of the control system. The adjustment time of the fuzzy PID control optimization system was 12 times less than that of the original system. The system overshoot was 36.5% less than the original system, and the rise time was 12% less than the original system [2]. Predictive automatic coupling PID (PAC-PID) control algorithm was used to design tobacco temperature and water content controllers. The system stability time was less than 16s, and the moisture deviation of exported tobacco leaves can be controlled within 1.5% [6]. Liu, Duan and Luo designed a tobacco cured barn with completely closed hot air cycle to perfect the curing quality of tobacco and avoid the loss of residual heat in bulk cured barn [7]. Li integrated PID control, fuzzy reasoning and expert system, so as to scientifically regulate the outlet water [8]. Rui et al. established an adaptive fuzzy PID controller and designed an intelligent control structure for water output during the blade charging process. The difference between the predicted moisture value at the outlet of the blade and the actual value was only 0.5%, the process capability index was 1.48 higher than that of the PID controller, and the return air temperature of the loader can be controlled to within the range of 56.86 C~57.21 C [9].

3.1.2. PID for Autonomous Car Technology. Autonomous car technology has become an important trend in the automotive industry. PID control is often used to optimize vehicle control technology to improve vehicle stability, reduce accident risk and optimize driving efficiency.

Chen et al. proposed an intelligent safe driving system for the problem that the wheel cylinder pressure of the traditional PID control braking system cannot meet the braking performance of the vehicle [10]. Zhong et al. designed a PID control strategy to suppress the torsional vibration generated by the APU during active control of the system [11]. Slide mode control of vehicle formation in uncertain topology was studied by Gao et al. [12]. Furthermore, optimal control can be enhanced by designing a preview controller that integrates road gradient, speed profile, and vehicle dynamics. The twiddle algorithm can also be used to adjust PID for trajectory tracking. GA was used to adjust PID to control DC motors. The radial basis function can be used to adjust the PID gain of vehicle longitudinal control[12]. Zhao et al. proposed an adaptive PID with GA optimization for lateral control tasks [12]. Moreover, NN PID has been proven to be used for frequency regulation and vehicle steering control [12].

While designed the control algorithms to track a given trajectory, Varma et al. found that MPC > LQR > PID(Performance Wise) for both Longitudinal speed control and Lateral steering control [13]. And Low-speed tracking can be used in the MPC [12]. Hu et al. suggested an adaptive algorithm for PID parameters of BP neural network in response to eh issue of oscillations when the learning rate of the traditional BP is too large in the learning process [14]. Given the difficult problem of energy management for traditional autonomous vehicles, an intelligent EMS for CAVs based on a fuzzy logic system and PID is proposed. The energy usage of vehicles improved about 9.58% [15]. To make full use of the attachment coefficient φ between the tire and the road surface, improve the power performance of the car and prevent driving roller skating, the method of using an artificial fish swarm algorithm can optimize the PID neural network control parameters of the vehicle [16]. A new global error function is proposed which can be fixed by PID using a heuristic optimization method and three black-box algorithms of GA, MA and MADS to optimize [3]. Similarly, Kebbati et al. found that PID controllers are difficult to tune and need additional adaptation to control nonlinear systems with varying parameters. So they achieved adaptive PID control using GA-PID and NN-PID longitudinal control, respectively [12]. In order to solve the problem of incremental PID control, a BP + RNN variable speed integral PID control system for the chassis dynamometer is proposed. The system can quickly set the PID parameters within 10 control cycles, and ensure that the control overshoot is within 2% of the target value [17]. Masromat et al. and Batiha et al. demonstrated that the PSO optimization algorithm can improve the efficiency of the system in terms of stability and anti-interference [18-19]. The PSO-based system improved by 9.3% and 28.4% over link 1 and link 2, respectively. The proposed controller can withstand disturbances 66.7% higher than the previous work, and the stabilization time after applying the interference is reduced from 8 seconds to 4 seconds [18]. The PID controller was improved by transforming it into the $PI^{\gamma}D^{\rho}$ [19].

3.2. PID for Mechanical Arm Robot

As an important part of the automation industrial system, mechanical arm robot plays an important role in service, exploration, automation engineering and other elds.

For the problems of the traditional mechanical arm and Sobel edge detection methods, including not being stable, time-consuming and impossible to obtain accurate object information. Lee proposed a new PID method and Canny edge detection algorithm [20]. Nonlinear control methods is facing difficulties, so El-Khatib and Maged considered a four degrees of freedom (4-DOF) robot arm model. Simple linear control methods are proposed to be used in the control of the angle of robot joints. For this purpose, the fuzzy logic controller (FLC) and the two degree of freedom PID (2-DOF PID) controller are applied to control the joint angles of robot arm and in order to improve the response speed and reduce overshoot [21]. Chotikunnan et al presented a method for optimizing membership function tuning for fuzzy control of robotic manipulators using PID-driven data techniques presented. It aims to enhance the precision and controllability of robotic manipulators through improved fuzzy logic control[22]. Moreover, Jawad et al. proposed a adaptive controller for robot arm manipulator based on the artificial Neural Network optimized PID by IWO. The maximum overshoot is equal to zero, the lift time is reduced to 0.1 in connector 3, the optimal establishment time is 0.2 in connector 1, and the delay time is reduced to 0.1 in connector 1 and 5[4]. Mohamed et al. propose six control structures to produce hybrid controllers for a 2-Link Rigid Robot Manipulator (2-LRRM) handling with the problem of trajectory tracking. The best performance of the proposed controllers was the Neural Network Fractional Order Proportional Integral Derivative Controller (NNFOPID)[23]. Wazzan et al. investigated traditional PID controller utilized Optimized social spider technique for robotic arm model. The fuzzy technique method has been inserted as artificial intelligence technique to introduce the better performance for robotic arm in utilize steady state error and positions for the coordination to all angles of robotic arms. The steady state error is zero and this work has been applied in MATLAB R2021a[24]. Furthermore, Pradhan and Subudhi proposed a new nonlinear self-tuning PID controller (NSPIDC) to control the joint position and link deflection of a flexible-link manipulator (FLM) while it is subjected to carry different payloads[25]. Azeez et al. introduced and compared two optimization techniques, the basic Artificial Bee Colony (ABC) and the enhanced Artificial Bee Colony with multi-elite guidance (MGABC), for determining optimal gains of a Proportional-Integral-Derivative (PID) controller in a 3 degrees of freedom (DOF) rigid link manipulator (RLM) system[26]. Through PID optimization, more artificial intelligence-related technologies have been applied to it, increasing the performance of the mechanical arm.

4. Discussion

PID control finds extensive application across various industries such as tobacco production, autonomous car technology, and mechanical arm robotics. In tobacco production, PID optimization enhances the dynamic response performance of control systems and enables scientific control of temperature and humidity levels, crucial for maintaining product quality. In autonomous car technology, PID controllers contribute significantly to improving vehicle stability, reducing accident risks, and optimizing driving efficiency by precisely regulating steering, acceleration, and braking actions based on real-time feedback. For mechanical arm robots, PID optimization boosts stability, precision, and response speed, crucial for executing precise movements and tasks in industrial automation and assembly operations.

Moreover, PID control's versatility can extend beyond these fields into others such as aerospace and aviation, where it plays a pivotal role in maintaining aircraft stability, controlling altitude, and managing flight dynamics. The adaptability of PID optimization allows for tailored applications within each domain, employing different tuning strategies to achieve optimal performance under specific operational conditions. So the future trends of PID application remain unpredictable. This may also due to ongoing advancements in control theory, artificial intelligence, and robotics, despite PID’s widespread adoption and effectiveness. Continued research and development are likely to further refine PID controllers, potentially integrating advanced techniques like machine learning and adaptive control to address evolving challenges and enhance overall system performance across diverse industrial and technological landscapes. Thus, while PID control continues to be a cornerstone in control engineering, its evolution and application in future innovations hold promise for further enhancing efficiency, safety, and precision in complex automated systems.

5. Conclusion

This study summarizes the optimization and application of PID control across tobacco production, autonomous car technology, and mechanical arm robotics. By integrating these sectors, it aims to provide a comprehensive analysis of PID's evolution, current implementation, and transformative impact within these industries.

In tobacco production, PID control optimizes dynamic response performance by precisely regulating environmental factors like temperature and humidity. This ensures consistent product quality and yield, crucial for agricultural sustainability and profitability. In autonomous car technology, PID controllers continuously adjust steering, acceleration, and braking in response to real-time feedback, improving vehicle stability, reducing accident risks, and enhancing driving efficiency. Similarly, in mechanical arm robotics, PID enhances stability, accuracy, and response speed, enabling precise task execution in industrial automation and assembly operations.

However, this study acknowledges limitations in primarily synthesizing existing literature without practical demonstrations to validate PID's effectiveness in real-world applications. Furthermore, it focuses narrowly on these three specific industries, omitting potential applications in other sectors such as aerospace, where PID also plays a significant role in flight control systems.

With further advancements in my academic studies, my understanding of PID will been deepened, enabling me to conduct empirical studies. This allows for a broader exploration. And more synthesis across various domains of PID applications can be done to expand the scope of my research and insights.

References

[1] Borase, R. P., Maghade, D. K., Sondkar, S. Y., & Pawar, S. N. (2021). A review of PID control, tuning methods and applications. International Journal of Dynamics and Control, 9, 818-827.

[2] He, Y., Wang, H., & Chen, D. (2020, December). The application of fuzzy PID control in the process temperature and humidity control of cigarette factory. In 2020 IEEE 9th Joint International Information Technology and Artificial Intelligence Conference (ITAIC) (Vol. 9, pp. 1091-1096). IEEE.

[3] Naranjo E, Serradilla F, Nashashibi F. Speed control optimization for autonomous vehicles with metaheuristics [J]. Electronics, 2020, 9(4): 551.

[4] Jawad, A. T., Ali, N. S., Abdullah, A. N., & Alwash, N. H. (2021, July). Design of adaptive controller for robot arm manipulator based on ANN with optimized PID by IWO algorithm. In 2021 International Conference on Advanced Computer Applications (ACA) (pp. 107-111). IEEE.

DOI: 10.54254/2755-2721/98/20241094

[5] Junhui, W., Jun, L., Yusheng, W., Jie, C., Huiping, S., & Kaiyan, L. (2020, November). Research on Electric Heating Cut Tobacco Dryer Based on Fuzzy PID Control Algorithm. In 2020 Chinese Automation Congress (CAC) (pp. 3884-3888). IEEE.

[6] Xie, J., & Jia, Z. (2021, May). Tobacco leaf redrying System Control based on Predictive Auto-Coupling PID. In Journal of Physics: Conference Series (Vol. 1906, No. 1, p. 012034). IOP Publishing.

[7] Liu, H., Duan, S., & Luo, H. (2022). Design and temperature modeling simulation of the full closed hot air circulation tobacco bulk curing barn. Symmetry, 14(7), 1300.

[8] Li, P. (2022). Expert system based moisture control system design for tobacco loose moisture export control system. Wireless Internet Technology, 19(9), 92-94.

[9] Rui, J., Qiu, D., Hou, S., Rong, J., Qin, X., Fan, J., ... & Zhu, C. (2023). Deep learning-based intelligent control of moisture at the exit of blade charging process in cigarette production. Applied Mathematics and Nonlinear Sciences, 9(1).

[10] Qian,Y., Yu, M., Guo, X., Huang, H., & Li, S. (2022). Development of Intelligent Control Technology for Driverless Vehicles. Science Technology and Engineering, 22(10), 3846-3858.

[11] Zhong B., Hou Z., & Liu R.. PID control of torsional vibration of auxiliary power unit during startup [J]. Automotive Engineering, 2018, 40(2): 143-149.

[12] Kebbati, Y., Ait-Oufroukh, N., Vigneron, V., Ichalal, D., & Gruyer, D. (2021, September). Optimized self-adaptive PID speed control for autonomous vehicles. In 2021 26th International Conference on Automation and Computing (ICAC) (pp. 1-6). IEEE.

[13] Varma, B., Swamy, N., & Mukherjee, S. (2020, October). Trajectory tracking of autonomous vehicles using different control techniques (pid vs lqr vs mpc). In 2020 International conference on smart technologies in computing, electrical and electronics (ICSTCEE) (pp. 84-89). IEEE.

[14] Hu, H., Zhao, S., Liu, Q., Wang, C., & Wang, T. (2020). BP neural network PID parameter tuning algorithm based on momentum factor optimized learning rate. Journal of Jilin University (Science Edition), 58(06), 1415-1420.

[15] Phan D, Bab-Hadiashar A, Hoseinnezhad R, et al. Neuro-fuzzy system for energy management of conventional autonomous vehicles [J]. Energies, 2020, 13(7): 13071745.

[16] Mai P. Research on vehicle anti-skid PID neural network con trol based on artificial fish swarm algorithm optimization[J]. Chinese Journal of Construction Machinery, 2020, 18(3): 215-219.

[17] Zhou Z., Chen Y., & Cheng X. Control system of vehicle chassis dynamometer based on BP, RNN variable speed integral PID algorithm[J]. Machinery Design & Manufacture, 2021 (2): 148-152.

[18] Masrom, M. F., A Ghani, N. M., & Tokhi, M. O. (2021). Particle swarm optimization and spiral dynamic algorithm-based interval type-2 fuzzy logic control of triple-link inverted pendulum system: A comparative assessment. Journal of Low Frequency Noise, Vibration and Active Control, 40(1), 367-382.

[19] Batiha, I. M., Ababneh, O. Y., Al-Nana, A. A., Alshanti, W. G., Alshorm, S., & Momani, S. (2023). A numerical implementation of fractional-order PID controllers for autonomous vehicles. Axioms, 12(3), 306.

[20] Lee, H. W. (2020). The study of mechanical arm and intelligent robot. IEEE Access, 8, 119624-119634.

[21] El-Khatib, M. F., & Maged, S. A. (2021, May). Low level position control for 4-DOF arm robot using fuzzy logic controller and 2-DOF PID controller. In 2021 International Mobile, Intelligent, and Ubiquitous Computing Conference (MIUCC) (pp. 258-262). IEEE.

[22] Chotikunnan, P., Chotikunnan, R., Nirapai, A., Wongkamhang, A., Imura, P., & Sangworasil, M. (2023). Optimizing Membership Function Tuning for Fuzzy Control of Robotic Manipulators Using PID-Driven Data Techniques. Journal of Robotics and Control (JRC), 4(2), 128-140.

[23] Mohamed, M. J., Oleiwi, B. K., Abood, L. H., Azar, A. T., & Hameed, I. A. (2023). Neural fractional order PID controllers design for 2-link rigid robot manipulator. Fractal and Fractional, 7(9), 693.
[24] Wazzan, A. N., Basil, N., Raad, M., & Mohammed, H. K. (2022). PID controller with robotic arm using optimization algorithm. Int. J. Mech. Eng, 7(2), 3746-3751.
[25] Pradhan, S. K., & Subudhi, B. (2018). Position control of a flexible manipulator using a new nonlinear self-tuning PID controller. IEEE/CAA Journal of Automatica Sinica, 7(1), 136-149.
[26] Azeez, M. I., Abdelhaleem, A. M. M., Elnaggar, S., Moustafa, K. A., & Atia, K. R. (2023). Optimization of PID trajectory tracking controller for a 3-DOF robotic manipulator using enhanced Artificial Bee Colony algorithm. Scientific reports, 13(1), 11164.