Review

PID Control Perspective: Techniques and Uses

Wisam Subhi Al-Dayyeni [1,*], and Hussam Saleh Mahmood [2]

[1] School of IT and Engineering, ADA University, Baku, Azerbaijan; wdayyeni@ada.edu.az
[2] Faculty of Science, Alexandria university, Alexandria, Egypt; Hussam.saleh_PG@alexu.edu.eg
* Correspondence: Tel.: +994 589 1446

Abstract: This article covers both conventional and modern methods for PID tuning and its applications in an array of fields. Because of its simple layout, ease of use, and ongoing research into PID tuning, PID control is used in the vast majority of control systems that are now in use. The following is the order of the tackles addressed in the paper: PID tuning occurs utilizing optimization rules that range from traditional to modern. In an age of control systems and biomedical applications, this work aims to examine the literature on PID control. A study of the evolution of conventional PID and its integration with intelligent control has been executed, taking into account a number of application fields. This document's main goal is to provide readers with an in-depth understanding of PID commands in many application areas.

Keywords: Process control; PID; Auto-tuning; Optimal PID control

1. Introduction

The PID controller has a longstanding history in the area of computerized control. By [1, 2] created by the steam engine and governor, which was recognized as the sooner adverse feedback mechanism. Moreover, a mathematical model was developed for the governor's control of the steam engine. It categorized the governors into two groups: moderators and authentic governors. In contemporary terminology, he characterizes moderators as controllers that utilize solely proportional control action, whereas authentic governors are defined as controllers that employ both proportional and integral control actions. Then, by [3], it presented a theoretical study of the derivative of mistake and its instantaneous rate of change. Their contribution, first dismissed by naval operators owing to personnel resistance, facilitated the later development of contemporary PID controllers.

The result of these two actions was that both controllers were provided with PID control. After several years, the issue of steady-state error in the proportional controller was mitigated by calibrating the setpoint to an arbitrary number until the error reached zero. This resetting "integrated" the error and became recognized as the proportional-integral controller [4]. The inaugural inflatable controller including derivative action was created, effectively reducing overshoot issues. However, the designers could not ascertain the suitable values for the PID controllers, when the adjustments and restrictions proposed by were adopted. Artificial PID controllers were widely utilized in factories around in [5, 6]. In subsequent phases, experts have concentrated on the adjustment of PID control, including self-tuning and auto-tuning [5, 7], genetic tuning of PID [8, 9], as well as strong and optimum adjustment [10], among others. Additionally, Smart PID and PID-based control strategies are presented in [11, 12], fuzzy PID in [13, 14], optimal PID controller design in [15, 16], adaptive PID control in [17], and fractional order PID in [18, 19].

Figure 1 illustrates that PID control utilizes several algorithmic ways: proportional, integral, and derivative. The proportional component integrates suitable proportional

Citation: To be added by editorial staff during production.

Academic Editor: Asst. Prof. Wurod Qasim Mohamed

Received: 29/11/2024
Revised: 28/12/2024
Accepted: 12/1/2025
Published: 17/1/2025

adjustments for mistake, defined as the discrepancy between the setpoint and the method factor, into the control response.

The integrated component analyzes the procedure constant throughout duration and adjusts the result to minimize the divergence from the processing constant. Derivative control method observes the pace of alteration of the process parameter and then adjusts the result in response to atypical fluctuations. The customer modifies every setting of each of the control mechanisms to get what they want from the entire procedure. Owing to its straightforward architecture, ease of execution, and repair, PID controllers are the most often utilized controllers in motion control, process control, power electronics, hydraulics, pneumatics, and industrial sectors, among others [20]. The PID controller provides outstanding functionality with a balance of costs and benefits that is challenging for other controller types to match. They are also ubiquitous in contemporary uses, such as autonomous vehicles, unmanned helicopters, and robotic systems, for analogous purposes [21]. In the majority of automation applications, 91-96% of control loops are of the PID configuration.

The present article originally concentrated on the fundamentals of PID and the PID tuning methodologies presented in prior publications. Subsequently, the research examines multiple fields in which the expressly utilized PID controller is analyzed, with the corresponding PID control methodologies employed in those areas. This article discusses the newest progress in PID, rendering it intelligent. The prospective research trajectory of PID control methodologies has been delineated.

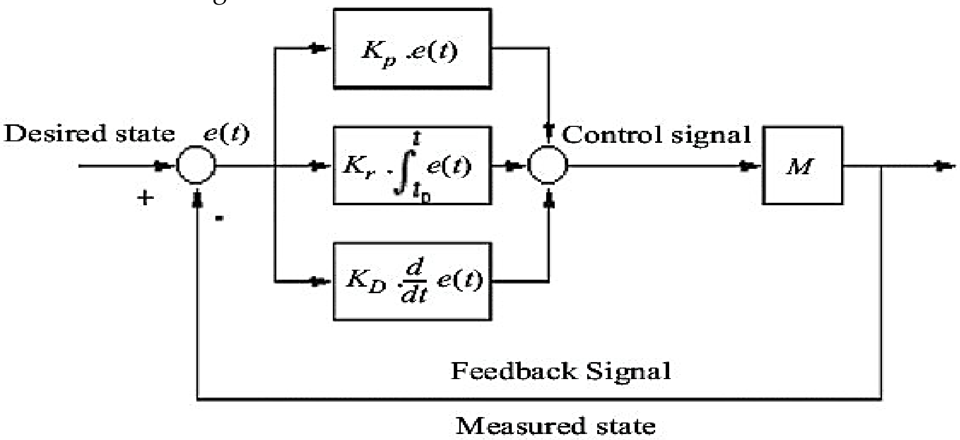

Figure.1 A schematic representation of industrial regulation with PID

2. Design and Adjustment Methodologies of PID Control Systems

2.1 Configurations of PID controllers with parameters

The series and parallel types of topologies are the most prevalent kinds of topologies used for PID devices: Type of Parallelism: Within this particular shape, the action of proportional P, integral I, or derivative D takes place in distinct solution phrases, and the total is created by the combined impact of these three actions. Individual parameters in this kind are not dependent on any other parameters, and the control rule that corresponds to them is shown as follows [21]:

$$U_t = K_p \times e_t + K_i \int e_t \times dt + K_p \times \frac{d_e}{d_t} \quad (1)$$

A PID controller receives the corresponding error signal (e), and its controller determines either the derivative of it and the total of this failure signal with regard to period. This error signal is subsequently transmitted to the controller. The proportional gain (kp) multiplied by the magnitude of the oversight, the integral gain (ki) multiplied by the integral of the mistake, and the gain from the derivative (kd) multiplied by the derivatives of the mistake are all components that make up the regulation signal (u) that is sent to the facility.

Series Sort: The series the formula, also known as an involved the formula, is primarily derived from the features of hydraulic and analogue electrical circuits. As is the case with an ideal PID the formula, changing it in has an effect on each of the activities; however, the impact on proportional action is exerted by both derivative and integral variables. For both types, figure 2 (a) and (b) can present series and parallel type respectively.

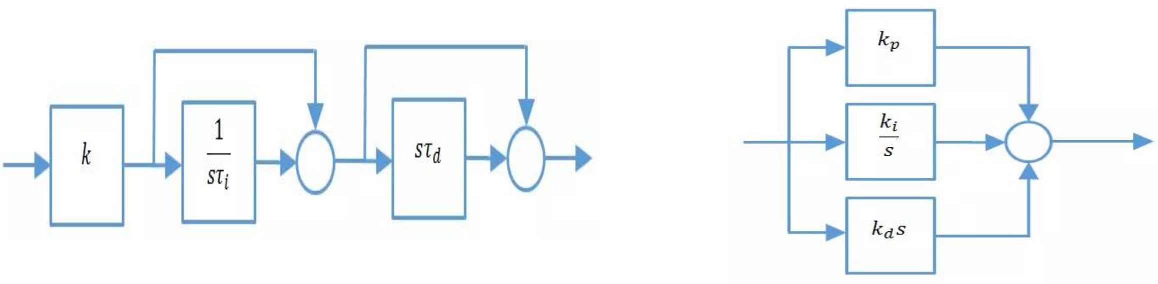

Figure.2 Configuration of PID (**a**) Series Type (**b**) Parallel Type

2.2 Tuning Methods

2.2.1 Traditional adjusting techniques

History identifies classical approaches for PID controller tuning, including the Ziegler–Nichols Frequency Response Method [22], Relay Tuning Method [23], and Cohen-Coon Procedure [24]. It has been discovered that about the proportion of processes deadtime to time stable, together with the cancellation of processes poles, mostly employs the PID controller. Classical tuning approaches rely on specific beliefs regarding the plant and the intended output, aiming to derive logical or visual characteristics of the process to inform the controller choices. These algorithms are straightforward to implement and exhibit rapid calculation. These strategies are effective in the early phase but fail to yield the intended outcomes consistently owing to underlying assumptions, necessitating further refinement.

2.2.2 Cognitive optimization techniques

The intricate structures and efficiency requirements of the controller architect need the development of novel adjusting design methodologies subsequent to the advent of traditional PID controller adjusting methods. Over decades of time, several. Significant understandings were acquired regarding PID tuning methodologies for enhanced performance-specific parameters and to address additional. Complex systems. Previously, traditional tuning approaches were exclusively applicable to first-order and second-order types. This is a disadvantage of conventional tuning approaches for PID regulation.

In Ref. [7], the authors suggested a more rapid tuning strategy and offered a Newton Raphson examination approach, which is to be easy, and it destroys the complicated root systems of the typical equation. in [25], it has been executed in different adjusting techniques for single-input single-output and multiple-input multiple-output process. The strategies are examined in many cases, and the results are time-delay systems and allocated parameter methods. then, some investigators donated the tuning techniques like auto-tuning [26], genetic algorithm strategy [9], model matching strategy [27], and unexplored PID tuning strategy [27], which were the essential elements of the mentioned strategy produced transfer function, reference standard, and linear equations which rely on Markov parameters. In ref. [28], it has also represented the auto-tuning method for choosing the tilting for the two-input two-output system. This approach has dual relay regulators employed to complete the required commonness as well as improvement of the method. In ref. [29], it has concentrated on combining and dangerous operations. They presented a systemic PI and PID tuning process, which relies on an optimum resonance specification to easy terms of the parameters. In Ref. [30], he offered unique PID tuning management based on scenario research and fuzzy logic tuning directions. In [31], he stated that improperly tuned, and tries to execute attack this issue systematically which easily manipulated and to analyze an irregular most delinquent efficient method. Lastly, an adaptive control technique relevant to these systems was presented with online tuning [32].

3. PID Programs

3.1 PID for Industrial Regulation

In industrial regulation, PID regulators are popularly employed and consequently recorded in the plurality of computerized regulation readers. It has proposed a strategy as a design support for inaccurate ON/OFF switches [33]. In refs [34, 35], a Self-tuning has been executed for status regulation of moisture tank and Aluminum. Ref. [36] has presented a recent multivariable self-tuning method for a class plus temperature regulation strategy. Additionally, [37] has donated by creating a relative evaluation of other adaptive regulation strategies for temperature techniques related on a Z to N strategy. In [38] These techniques are employed in eclectic topics for high-order dynamics. The proposed tuning method in this reference depends on the view of the system. The regard ideal for an easy second-order method was described as:

$$Y(s) = \frac{\omega_n^2}{S^2+2\varsigma\omega_2 s+\omega_n^2} \tag{2}$$

$$Y_{(t)} = \beta^T \times \theta_{t-1} \tag{3}$$

$$\beta = [a_1, a_2, a_3, a_4, \ldots., a_n\; b_1, b_2, \ldots., b_n]^T \tag{4}$$

$$\theta_{t-1} = [Y_{t-1}, Y_{t-2}, Y_{t-3}, Y_{t-4}, \ldots., Y_{t-n}]^T \tag{5}$$

$$\beta_t^{/} = \beta_{t-1}^{/} + W_t \times \theta_{t-1} \times (Z_t - \beta^{/T} \times \theta_{t-1}) \tag{6}$$

$$W_t = [0,1]^{-1}(W_{t-1} - W_{t-1} \times \theta_{t-1} \times \theta_{t-1}^T([0,1] + \theta_{t-1} \times \theta_{t-1}^T)^{-1}) \tag{7}$$

For all parameters in Eq.(s) are founded in ref. [39], see them there for more information. Also, a lot of investigators carried out forward PID control techniques for different approaches and their applications in [40, 41] and in [42, 43]. In [44] presents dynamic disorder denial power for the creation of a maximum PID controller for a related tank design.

3.2 PID for Automated Operators

Notwithstanding advancements in current concepts of control, robot manipulation circuits frequently employ traditional PD or PID methods, mainly owing to their conceptual elegance and straightforward adjustment processes. There are a lot of researchers work in this fields of automated operation like [45] based on distributed signal derived through the calculated energy, [46] best PID numerically executed, [47, 48] the constancy of PID regulator for commercial robotic manipulators, [49] complicated simulation exhibiting analogous behaviors, [50, 51] flexible configuration.

Investigation concerning PID controllers used to operate robots is divided into three domains. The initial field encompasses the adjustment of PID advantages by the implementation of smart control methods, such as fuzzy logic control, neural networks, and genetic methods [52, 53]. The next study field focuses on PID increase selection techniques utilizing control approaches, including optimum policies [54, 55]. The final category of study focuses on PID obtain choices employing explicit analysis of stability through Lyapunov resilience [56, 57].

3.3 PID Control for Engines and Energy Uses

Briefly, the execution of PID regulation for the converter from DC to DC was conducted by ref [58, 59]. PID rely on control techniques are successfully used in power plant and electrical energy plant operations [60, 61].

3.4 PID Control for Medical Devices

Diverse PID rely on control methodologies have been suggested for medical uses, including blood vessel pressure infusion and legislation, reducing muscle tension in surgical recipients, angle of motion control for deliberately triggered muscles, transplanted livers, and blood sugar oversight

An advanced PID controller and enhanced PID changing control for managing blood sugar are presented in [62, 63]. A PID controller is employed to mimic a kidney [64]. Strong PID control is presented for the management of This drug sedation for kids [65].

3.5 PID Control for Dynamical Processes

In business, the majority of machinery are regulated by PID control methods. Investigations conducted on PID control methodologies relevant to dynamic magnetism brake, cutting processes, quadrotors, static tension management systems, gravity structures, piloting cranes, and grippers.

PID control algorithms are implemented for levitating in references [66, 67]. A saturation relies on adjusting approach for a fuzzy PID controller is developed to regulate arm spin [68]. A new study has developed optimum partial fuzzy PID control [69].

4. Conclusions and Prospective Study Directions

An exhaustive review indicates that the PID controller is probably the most prevalent controller across all areas due to its straightforward form and ease of deployment. The novel characteristics of automated adjustment have significantly streamlined the application of PID control. A while ago, fractional-order PID integrated with fuzzy logic systems, IMC-PID controller design, optimum PID control, and the integration of PID-observer structures have garnered increasing interest.

In the near term, PID-based control methods, including optimum fractional order PID, fractional fuzzy PID, and self-tuning PID, will be extended for use in arithmetic management systems. Furthermore, it might be stated that the PID has an autonomous tuning capability, that has garnered increased interest from businesses. The optimization of PID controllers is a significant study domain.

Acknowledgments: The authors declare, there is no any grant that support this work.

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest."

References

1. Kang, C.-G., *Origin of Stability Analysis:\" On Governors\" by JC Maxwell [Historical Perspectives].* IEEE Control Systems Magazine, 2016. **36**(5): p. 77-88.
2. Nayak, R. and T. Abdul Munem Abdul Razaq, *Examination of the Perspective Regulator of Civil Quad-Rotor UAV Relay on F-PID Controller.* Edison Journal for electrical and electronics engineering, 2023. **1**: p. 6 - 10.
3. Medaglia, J.D., *Clarifying cognitive control and the controllable connectome.* Wiley Interdisciplinary Reviews: Cognitive Science, 2019. **10**(1): p. e1471.
4. Bennett, S., *The past of PID controllers.* IFAC Proceedings Volumes, 2000. **33**(4): p. 1-11.
5. Bennett, S., *Development of the PID controller.* IEEE Control Systems Magazine, 1993. **13**(6): p. 58-62.
6. Fong-Chwee, T. and H. Sirisena, *Self-tuning PID controllers for dead time processes.* IEEE Transactions on industrial electronics, 1988. **35**(1): p. 119-125.
7. Rad, A.B., W.L. Lo, and K. Tsang, *Self-tuning PID controller using Newton-Raphson search method.* IEEE Transactions on Industrial Electronics, 1997. **44**(5): p. 717-725.
8. Zhuang, M. and D. Atherton. *Automatic tuning of optimum PID controllers*. in *IEE Proceedings D (Control Theory and Applications)*. 1993. IET.
9. Porter, B. and A. Jones, *Genetic tuning of digital PID controllers.* Electronics letters, 1992. **28**(9): p. 843-844.
10. Kristiansson, B. and B. Lennartson, *Robust and optimal tuning of PI and PID controllers.* IEE Proceedings-Control Theory and Applications, 2002. **149**(1): p. 17-25.
11. Hsieh, C.-H. and J.-H. Chou, *Design of optimal PID controllers for PWM feedback systems with bilinear plants.* IEEE transactions on control systems technology, 2007. **15**(6): p. 1075-1079.
12. Chan, Y.F., M. Moallem, and W. Wang, *Design and implementation of modular FPGA-based PID controllers.* IEEE transactions on Industrial Electronics, 2007. **54**(4): p. 1898-1906.
13. Sio, K. and C. Lee, *Stability of fuzzy PID controllers.* IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 1998. **28**(4): p. 490-495.
14. Tzafestas, S. and N.P. Papanikolopoulos, *Incremental fuzzy expert PID control.* IEEE Transactions on Industrial Electronics, 1990. **37**(5): p. 365-371.
15. SLS0SS, S.S.S.S.S.S. *Optimal setting for discrete PID controllers*. in *IEE PROCEEDINGS-D*. 1992.
16. Tang, K.-S., et al., *An optimal fuzzy PID controller.* IEEE transactions on industrial electronics, 2001. **48**(4): p. 757-765.
17. Kaya, Y. and S. Yamamura, *A self-adaptive system with a variable-parameter PID controller.* Transactions of the American Institute of Electrical Engineers, Part II: Applications and Industry, 1962. **80**(6): p. 378-386.
18. Zhenbin, W., et al., *Digital implementation of fractional order PID controller and its application.* Journal of Systems Engineering and Electronics, 2005. **16**(1): p. 116-122.
19. Viola, J. and L. Angel, *Factorial design for robustness evaluation of fractional PID controllers.* IEEE Latin America Transactions, 2015. **13**(5): p. 1286-1293.
20. Åström, K.J. and T. Hägglund, *The future of PID control.* Control engineering practice, 2001. **9**(11): p. 1163-1175.
21. Díaz-Rodríguez, I.D., S. Han, and S.P. Bhattacharyya, *Analytical design of PID controllers*. 2019: Springer.
22. Ziegler, J.G. and N.B. Nichols, *Optimum settings for automatic controllers.* Transactions of the American society of mechanical engineers, 1942. **64**(8): p. 759-765.
23. Åström, K.J. and T. Hägglund, *Automatic tuning of simple regulators.* IFAC Proceedings volumes, 1984. **17**(2): p. 1867-1872.
24. Ho, W.K., et al., *Performance and gain and phase margins of well-known PID tuning formulas.* IEEE Transactions on Control Systems Technology, 1996. **4**(4): p. 473-477.
25. Koivo, H. and J. Tanttu, *Tuning of PID conrollers: Survey of SISO and MIMO techniques*, in *Intelligent tuning and adaptive control*. 1991, Elsevier. p. 75-80.

26. Ruano, A., P. Fleming, and D. Jones. *Connectionist approach to PID autotuning*. in *IEE Proceedings D (Control Theory and Applications)*. 1992. IET.
27. Aguirre, L., *PID tuning based on model matching.* Electronics Letters, 1992. **28**(25): p. 2269-2271.
28. Zhuang, M. and D. Atherton, *PID controller design for a TITO system.* IEE Proceedings-Control theory and applications, 1994. **141**(2): p. 111-120.
29. Poulin, E. and A. Pomerleau, *PID tuning for integrating and unstable processes.* IEE Proceedings-Control theory and applications, 1996. **143**(5): p. 429-435.
30. Visioli, A., *Tuning of PID controllers with fuzzy logic.* IEE Proceedings-Control Theory and Applications, 2001. **148**(1): p. 1-8.
31. Cominos, P. and N. Munro, *PID controllers: recent tuning methods and design to specification.* IEE Proceedings-Control Theory and Applications, 2002. **149**(1): p. 46-53.
32. Huang, H.-P., M.-L. Roan, and J.-C. Jeng, *On-line adaptive tuning for PID controllers.* IEE Proceedings-Control Theory and Applications, 2002. **149**(1): p. 60-67.
33. Stafford, E., *Design aid for approximate PD and PID on/off controllers.* Electronics Letters, 1977. **13**(6): p. 163-164.
34. Lennartson, B. and B. Kristiansson, *Evaluation and tuning of robust PID controllers.* IET control theory & applications, 2009. **3**(3): p. 294-302.
35. Jacobs, O., P. Hewkin, and C. While. *Online computer control of pH in an industrial process*. in *IEE Proceedings D (Control Theory and Applications)*. 1980. IET.
36. Yamamoto, T. and S. Shah, *Design and experimental evaluation of a multivariable self-tuning PID controller.* IEE Proceedings-Control Theory and Applications, 2004. **151**(5): p. 645-652.
37. Gawthrop, P., P. Nomikos, and L. Smith. *Adaptive temperature control of industrial processes: a comparative study*. in *IEE Proceedings D (Control Theory and Applications)*. 1990. IET.
38. Daley, S. and G. Liu, *Optimal PID tuning using direst search algorithms.* Computing & Control Engineering Journal, 1999. **10**(2): p. 51-56.
39. Somefun, O.A., K. Akingbade, and F. Dahunsi, *The dilemma of PID tuning.* Annual Reviews in Control, 2021. **52**: p. 65-74.
40. Dinca, M.P., M. Gheorghe, and P. Galvin, *Design of a PID controller for a PCR micro reactor.* IEEE Transactions on Education, 2008. **52**(1): p. 116-125.
41. Papadopoulos, K.G., E.N. Papastefanaki, and N.I. Margaris, *Explicit analytical PID tuning rules for the design of type-III control loops.* IEEE Transactions on Industrial Electronics, 2012. **60**(10): p. 4650-4664.
42. Eslami, M., M.R. Shayesteh, and M. Pourahmadi, *Optimal design of PID-based low-pass filter for gas turbine using intelligent method.* IEEE Access, 2018. **6**: p. 15335-15345.
43. Razvarz, S., et al., *Flow control of fluid in pipelines using PID controller.* IEEE Access, 2019. **7**: p. 25673-25680.
44. Garran, P.T. and G. Garcia, *Design of an optimal PID controller for a coupled tanks system employing ADRC.* IEEE Latin America Transactions, 2017. **15**(2): p. 189-196.
45. Bestaoui, Y. *Decentralised PD and PID robotic regulators*. in *IEE Proceedings D (Control Theory and Applications)*. 1989. IET.
46. Zhang, H., G. Trott, and R. Paul, *Minimum delay PID control of interpolated joint trajectories of robot manipulators.* IEEE Transactions on Industrial Electronics, 1990. **37**(5): p. 358-364.
47. Rocco, P., *Stability of PID control for industrial robot arms.* IEEE transactions on robotics and automation, 1996. **12**(4): p. 606-614.
48. Sun, D., et al., *Global stability of a saturated nonlinear PID controller for robot manipulators.* IEEE Transactions on Control Systems Technology, 2009. **17**(4): p. 892-899.
49. Feng, W., J. O'reilly, and D. Ballance, *MIMO nonlinear PID predictive controller.* IEE Proceedings-Control Theory and Applications, 2002. **149**(3): p. 203-208.
50. Parra-Vega, V., et al., *Dynamic sliding PID control for tracking of robot manipulators: Theory and experiments.* IEEE Transactions on Robotics and Automation, 2003. **19**(6): p. 967-976.

51. Jafarov, E.M., M.N.A. Parlakçi, and Y. Istefanopulos, *A new variable structure PID-controller design for robot manipulators.* IEEE Transactions on Control Systems Technology, 2004. **13**(1): p. 122-130.
52. Li, W., et al., *Tracking control of a manipulator under uncertainty by FUZZY P+ ID controller.* Fuzzy Sets and Systems, 2001. **122**(1): p. 125-137.
53. Kazemian, H.B., *The SOF-PID controller for the control of a MIMO robot arm.* IEEE Transactions on Fuzzy Systems, 2002. **10**(4): p. 523-532.
54. Park, J. and W.K. Chung, *Analytic nonlinear H/sub/spl infin//inverse-optimal control for Euler-Lagrange system.* IEEE Transactions on Robotics and Automation, 2000. **16**(6): p. 847-854.
55. Park, J. and W. Chung, *Design of a robust H∞ PID control for industrial manipulators.* J. Dyn. Sys., Meas., Control, 2000. **122**(4): p. 803-812.
56. Eriksson, E. and J. Wikander. *Robust PID design of flexible manipulators through pole assignment*. in *7th International Workshop on Advanced Motion Control. Proceedings (Cat. No. 02TH8623)*. 2002. IEEE.
57. Alavarez-Ramirezi, J., I. Cervantes, and R. Bautista. *Robust PID control for robots manipulators with elastic joints*. in *Proceedings of the 2001 IEEE International Conference on Control Applications (CCA'01)(Cat. No. 01CH37204)*. 2001. IEEE.
58. Kapat, S. and P.T. Krein, *Formulation of PID control for DC–DC converters based on capacitor current: A geometric context.* IEEE Transactions on Power Electronics, 2011. **27**(3): p. 1424-1432.
59. Seo, S.-W. and H.H. Choi, *Digital implementation of fractional order PID-type controller for boost DC–DC converter.* IEEE Access, 2019. **7**: p. 142652-142662.
60. Alhafadhi, M.H., M.J. Ahmed, and H.H. Ibrahim, *Load Frequency Control for Hybrid Power System by Modified PSO-PID Controller.* Edison Journal for electrical and electronics engineering, 2024. **2**(1): p. 35-41.
61. Behera, A., et al., *A novel cascaded PID controller for automatic generation control analysis with renewable sources.* IEEE/CAA Journal of Automatica Sinica, 2019. **6**(6): p. 1438-1451.
62. Chee, F., et al., *Expert PID control system for blood glucose control in critically ill patients.* IEEE Transactions on Information Technology in Biomedicine, 2003. **7**(4): p. 419-425.
63. Marchetti, G., et al., *An improved PID switching control strategy for type 1 diabetes.* ieee transactions on biomedical engineering, 2008. **55**(3): p. 857-865.
64. O'Hara, D.A., et al., *The use of a PID controller to model vecuronium pharmacokinetics and pharmacodynamics during liver transplantation.* IEEE transactions on biomedical engineering, 1997. **44**(7): p. 610-619.
65. Van Heusden, K., et al., *Design and clinical evaluation of robust PID control of propofol anesthesia in children.* IEEE Transactions on Control Systems Technology, 2013. **22**(2): p. 491-501.
66. Wai, R.-J., J.-D. Lee, and K.-L. Chuang, *Real-time PID control strategy for maglev transportation system via particle swarm optimization.* IEEE Transactions on Industrial Electronics, 2010. **58**(2): p. 629-646.
67. Chen, Q., et al., *Decentralized PID control design for magnetic levitation systems using extremum seeking.* IEEE Access, 2017. **6**: p. 3059-3067.
68. Duan, X.-G., H. Deng, and H.-X. Li, *A saturation-based tuning method for fuzzy PID controller.* IEEE Transactions on Industrial Electronics, 2012. **60**(11): p. 5177-5185.
69. Meng, F., S. Liu, and K. Liu, *Design of an optimal fractional order PID for constant tension control system.* IEEE Access, 2020. **8**: p. 58933-58939.