INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 3 (2024) 107-117
https://publisher.uthm.edu.my/ojs/index.php/ijie

Hybrid Sliding Mode Control with Gain Scheduling Proportional Integral Derivative Controller for Water Tank System

Anith Khairunnisa Ghazali[1], Nor Azlina Ab Aziz[1]*, Wan Zakiah Wan Ismail[2]

[1] *Faculty of Engineering & Technology, Multimedia University, Melaka 75450, MALAYSIA*

[2] *Faculty of Engineering & Built Environment, Universiti Sains Islam, Nilai, 71800, MALAYSIA*

*Corresponding Author: azlina.aziz@mmu.edu.my
DOI: https://doi.org/10.30880/ijie.2024.16.03.011

Article Info

Received: 13 December 2023
Accepted: 5 March 2024
Available online: 30 April 2024

Keywords

Water tank, water level, proportional integral derivative, sliding mode controller, gain scheduling

Abstract

Water storage tank is important in many industries. A tank's water level must be kept at a particular desired level in order for the process to run as designed in manufacturing industry, efficient farming management in agriculture sector and many other reasons. An important issue of water level management in storage tanks is the control issue in closed-loop. The proportional integral derivative (PID) controllers are popularly applied for controlling liquid level. The limitation of PID controllers is that they are feedback-type controllers, where control action is only taken when the output is affected by error. However, conventional PID controllers are unable to effectively maintain liquid level, so the need for performance improvement in the current liquid level regulators is crucial. This research implement hybrid sliding mode controller with PID tuning gain scheduling (SMC-GSPID) controller to improves the robustness of the system. In addition, the conventional PID has been tested using three control methods of tuning which is Ziegler Nichols, Tyreus Luyben and Cohen Coon for comparison with the proposed method. All the results are validated using Matlab Simulink. The performance is evaluated using overshoot and steady state error for each controller. Based on the simulations, the suggested approach offers superior level position tracking performance with high precision compared to other PID control method with minimum overshoot of 2.9%, zero steady state error and shortest rise time which is 1.9 sec.

1. Introduction

Processes and systems become more complex as science and technology advance. There are many systems with large, complex, and strongly nonlinear characteristics. Water is a key natural resource that is used in a variety of sectors including, chemical industry, commercial, and agricultural operations. Water is also very critical in sustaining life. Water mishandling and management cause wastage of this valuable resource and have a negative impact on the sustainability of our ecosystem [1].

Level control is an important component of process control systems' control loops in many industries. In process industries and the wastewater treatment sector, level control is widely used [2]. For example, reactant mixing is a widely used technique in the food and chemical processing industries. The fluid level in the tanks must always be maintained within the desired level to ensure that the process runs smoothly and that the products are of higher quality[3]. The level and flow control is very laborious, and the control loop for this control can either be a single loop or multiple loop system.

The goal of level control is to make the water level or other liquids such as oil and chemical liquid adapt to a predetermined value or to immediately restore a steady level in the event of a disturbance [4]. Usually, on-off loop control schemes with only the relay device and the limit switch are used in liquid tank level systems. However, this type of system is prone to wastage when the users forget to turn off the motor after turning it on. This consequently can results in a water shortages [5]. Another common issues of water level control are; (1) with the overflow control, which acts to prevent a storage tank from exceeding its maximum capacity, and (2) for tank with fully drain, a system which prevents the pump from working without liquid [6]. Therefore, a more advanced and efficient liquid tank's level control system is needed. However, there are numerous challenges in the design of liquid tank's level control system [7]. Since it is difficult to attain exact position level control, this precision control requires modifications to improve the performance.

Numerous engineers have created linearized simulations of actual tank systems using the conventional controllers like the proportional integral derivative (PID) controller. However, due to the complexity and nonlinearity of the real processes, it is difficult to improve the performance of the systems [8] and the solution is not entirely practical to be applied in industry [9].

The sliding mode control (SMC) technique, is one of the most well-known nonlinear control strategies. Up to this point, numerous SMC schemes are available for various complex systems including water level control [10]. SMC has proven to be a successful method for controlling nonlinear systems with uncertainties because of its resistance to parameter changes and outside disturbance [7]. Additionally, SMC has the advantages of quick response and high robustness. It also offers a systematical solution to the issue of preserving accuracy, robustness, stability, ease of tuning, and consistent performance in the face of imprecise modelling [11]. SMC method is also good in dealing with system uncertainties and disturbances [12].

Several works had shown that hybridization of controllers may contribute to better systems. For example, in [13] SMC controller and PID controller are combined through fuzzy logic for induction motor and found to have faster rising time while the motor is able to achieve targeted speed sooner. Two hybrid SMC controllers are proposed for pH process control in [14]. The proposed hybrid controllers give better performance and more robust system. Similarly hybrid controllers reported in [15,16] also reported improved performance compare to traditional controller. Therefore, this work proposed a hybrid SMC with PID tuning gain scheduling (SMC-GSPID) controller for water tank's level control system. The proposed system is compared with Tyreus Luyben, Cohen Coon, and Ziegler Nichols control systems.

This paper is organized into five sections. Here in section 1 the research work and research background are briefly introduced. Second section discusses the related works. Next in section three, the design of the conventional PID controller and hybrid SMC-GSPID controller for water tank is presented. Section 4 presents the findings of the proposed SMC-GSPID and the output is compared with Tyreus Luyben (TL), Cohen Coon (CC), and Ziegler Nichols (ZN) tuned PID controller. Lastly, section 5 concludes the work based on the findings and suggestions for future works.

2. Related Work

The traditional PID control system algorithm is straightforward, and made a significant improvement in control loop performance by providing satisfactory results in terms of response time and control accuracy [17]. Despite their straightforward design and reliable performance, and the popularity of this controllers being used in industries, the performance of the PID controller's parameters tuning is poor, making it difficult to achieve the desired control effect when the controlled objects have non-linear, time-varying uncertainty [18]. The TL, CC and ZN are popular methods for tuning PID controller. This section looks into existing works on liquid level control using these popular methods and other related works.

In research by Vinothkumar and Esakkiappan for tank's level control in pharmaceutical industry, the authors compared CC and ZN method and study their behavior. According to the results, CC performs better than ZN, whose PID method takes 307 seconds and whose proportional integral (PI) method takes 405 seconds to settle, meanwhile the CC has faster settling times of 111 seconds for PID and 189 seconds for PI [19].

According to the error analysis conducted in reference [20], the tuning approach for the PID controller in the hopper tank achieved satisfactory performance. The system exhibited less aggressive oscillation and a rapid settling reaction when subjected to an 80% step input. It also demonstrates a quick settling response and a positive disturbance rejection outcome. An analysis of ZN and TL tuning reveals that TL exhibits reduced overshoot and a more rapid response time in monitoring changes in set point when compared to ZN.

Gain scheduling (GS) methods is proposed in [21]. The results demonstrate that the GS-based control systems provide zero steady-state control error, short settling times, and minimal overshoots with respect to changes towards the reference input. Meanwhile, Pratama et al. proposed a GS PID with back calculation integrator anti windup for nonlinear water tank system. The results show that GS PID outperforms conventional PID controllers in terms of rise and settling time. GS PID controller demonstrates that it is adaptable to change in process variables and maintains the set point specified by the user [22].Merlin et al. proposed GS PI controller for conical tank system and then compared it with conventional PI controller [23]. Based on the results, the proposed controller gives better performance with better transient response and steady state response.

A standard SMC and integral SMC was proposed in [24] to reduce chattering issues. The asymptotic stability of the closed loop system is ensured by the proposed control techniques. Based on the results integral SMC is able to reduce chattering and yield smoother control signal compared to standard SMC. In addition, [25] also introduce SMC controller for coupled tank system. The outcome of adjusting various SMC parameter values yields a better response with no overshoot and a shorter settling time.

A research from Chirita et al [26]., proposed SMC for liquid level control of twin tanks. The proposed controller was implemented in a closed loop system and evaluated with various types of input signals and disturbances using simulation. Based upon the results, SMC is able to control the system with its robust behavior for various input signals or parameter values. SMC outperformed the PID controller for the step command on all indicators.

SMC is also applied for controlling other systems. Baofeng et. al, proposed the permanent magnet flux observer based on SMC [27]. Based on the simulation results, demonstrate that SMC can more precisely estimate the rotor flux of permanent magnet synchronous motors. The vector control system based on the flux observer can adjust the speed of the permanent magnet synchronous motor over a broad range; this control system's sliding mode observer has excellent static and dynamic performance.

In addition, a model-free based fuzzy sliding mode control (MFSDF-SMC) is proposed for controlling the attitude and positions of an underactuated quadrotor unmanned aerial vehicle (UAV) in [28]. The simulation results demonstrate the robustness of the proposed algorithm for the stability and control of an underactuated quadrotor UAV during aggressive maneuvers, as well as for tracking the helical trajectory in the presence of unmodeled dynamic factors and external disturbances.

Vu et al. [29] present the design and implementation of an optimal fuzzy augmented sliding mode control strategy for a Stewart parallel robot platform. External disturbances were applied to a Stewart platform with six degrees of freedom in order to validate the proposed method. In comparison, its performance is that of a conventional SMC method. Its performance is compared to a classical SMC approach, and the comparative research results show that the suggested control algorithm is capable of reducing chattering and successfully responding to actual control energy demands while preventing actuator saturation.

From existing works, it can be observed that TL, CC, ZN, GS and SMC are popularly adopted in design of liquid tank's level control system. The GS and SMC reported good performance thus frequently used. In other applications, SMC is also providing good performance. According to previous research findings, there are no existing research that proposed the SMC with GS PID tuning for water tanks, particularly focusing on rise time, steady state and overshoot. Therefore, hybrid of SMC with GS PID controller for water tank system is proposed here.

3. Methodology

The tank water level control system's goal is to eliminate all obstructing elements so that the water level remains constant. The water level control system's structure consists of a pipeline connecting liquid lines, valves, water tanks, liquid level sensors, water pumps, and electric regulating valves [30]. Tank level controllers and gain scheduled PID controllers are adaptable, and the tank level controller exhibits linear characteristics at different operating points [31]. The mechanism's operation of this system depends on determining the error value, which is the discrepancy between the desired and actual values. The controller will change the valve based on the error value to keep the tank level constant. The block diagram of the system is as illustrated below in Fig 1.

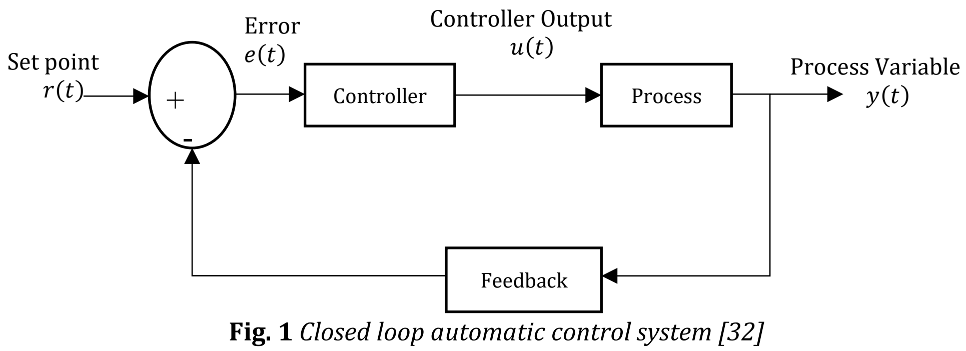

Fig. 1 *Closed loop automatic control system [32]*

3.1 Mathematical Model

Fig 2 illustrate a simple single water tank system. If the inflow rate of the water tank, Q_i, and the outflow rate of the tank outlet, Q_0, are equal, the water level of the tank, H, remains constant. The relationship between the input, Q_i, and the output, Q_0, of the water tank system can be modelled as a single-input single-output (SISO) system. The rate of level change can be expressed as in Eq (1) when the inflow or outflow rate changes:

$$A\frac{dH}{dt} = Q_i - Q_0 \tag{1}$$

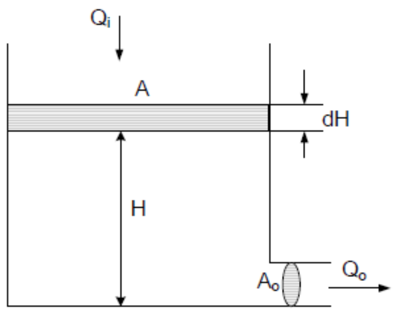

Fig. 2 *Single water tank system [4]*

According to Bernoulli's equation, the speed of water tank outlet is written as $v = \sqrt{2gH}$ $[cm/s]$, and the outlet flow rate, Q_0 $[cm^3/s]$ can be calculated by multiplying this speed by the water tank outlet's cross sectional area, $A_0[cm^2]$. Additionally, in order to express Q_0, the fluid resistance at the water tank outlet, R, can be used. Thus, the following expressions (Eq. 2) can be used.

$$Q_0 = A_0\sqrt{2gH} = \frac{1}{\mathrm{R}}H \tag{2}$$

The resistance is given in Eq. 3,

$$\mathrm{R} = \frac{dH}{dQ} = \frac{H}{Q_0} \tag{3}$$

Substituting Eq (2) into Eq (1) gives,

$$A\frac{dH}{dt} = Q_i - \frac{H}{\mathrm{R}} \tag{4}$$

$$\mathrm{R}A\frac{dH}{dt} + H = \mathrm{R}Q_i \tag{5}$$

Taking the Laplace transform by considering initial conditions to zero, yields

$$RAs + H(s) = RQ_i(s) \tag{6}$$

The transfer function for the whole system is then expressed in Eq. 7 below,

$$\frac{H(s)}{Q_i(s)} = \frac{R}{RAs + 1} \tag{7}$$

3.2 Controller Design

The purpose of this work is to introduce an automated water tank control system, which automatically controls the levels of water, preventing overflow from the overhead tank and controlling the level of water below the determined margin. The system is controlled using a proposed hybrid controller SMC-GSPID system.

3.2.1 Sliding Mode Control

SMC is a type of variable structure control system that is distinguished by a discontinuous feedback control scheme that switches as the system crosses a certain manifold in the state space to force the system state to reach, and then remain on, a specified surface within the state space known as the sliding surface [33]. Since the system model is used to derive the control law, the time required for the system states to reach the sliding surface is dependent on the incline of the sliding surface and the precision of the system model. In sliding mode, the objective is to maintain the system's dynamics on the predefined sliding surface to force the error dynamics to the origin. Fig 3 illustrates sliding surface of sliding mode control.

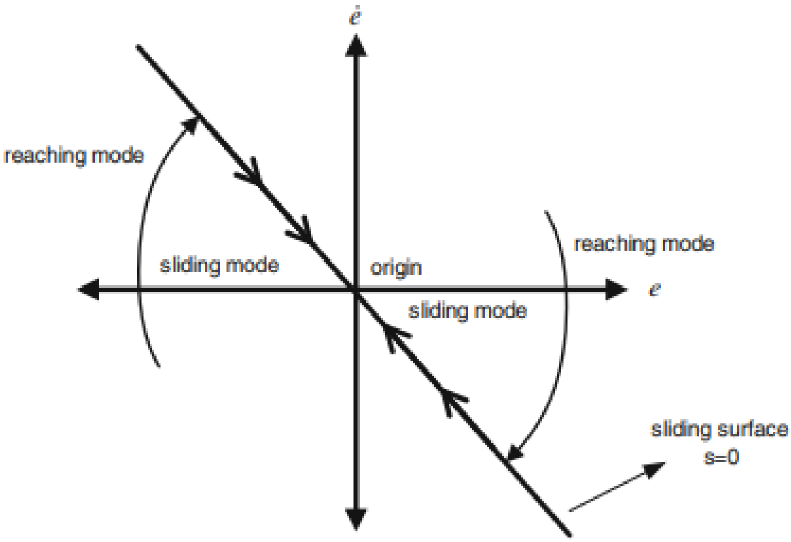

Fig. 3 *Sliding surface*

The design of the sliding function S(t) is the most crucial step in SMC configuration. The sliding function for nth order system is written as follows. If S(t) is the time-varying surface, then S(x;t)=0 by scalar function, where;

$$S(t) = \left(\frac{d}{dt} + \lambda\right)^{(n-1)} e \tag{8}$$

Since n stands for the system order and the plant transfer function is second order, n=2, the Eq. 8 is reduced to Eq.9. provides a sliding function that can be used to represent a second order system.

$$S(t) = \left(\frac{d}{dt} + \lambda\right)^{1} e = \dot{e} + \lambda e \tag{9}$$

Where λ=0 is the slope of sliding surface [34].

3.2.2 PID Controller

PID controller can guarantee satisfactory performances with a straightforward algorithm for a variety of processes [17]. Due to the diversity of the components operating within this controller, it is also unique in terms of capabilities [35].

There are three gain parameters for the PID controller that can be changed or tuned for better performance. The simplest tuning method is through trial and error [36]. The PID controller's S-domain transfer function is expressed in Eq. 8 below [37].

$$C(s) = K_P\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{10}$$

3.2.3 Gain Scheduling

GS is one of the most crucial methods for embedding nonlinearities into some linear time-varying parameters that rely on the conditions of the system, its inputs and outputs, or the environment [38]. It is applied to the design of reliable controls. This approach is recommended if the plant's parameters change frequently. The set of controller parameters or various plant sets are found using this method. Typically, slow-moving plant dynamics are required for this type of control strategy [39]. A GS control scheme generates a non-linear global controller by tuning a series of local controllers at specific operation points. The global controller's parameters are updated continuously as plant operating conditions change throughout the entire operating area. This change is detected by changing a suitable variable, which is chosen to be the scheduling variable [40].

3.2.4 Hybrid SMC-GSPID for Water Tank Control

The closed loop of water tank control system is designed as illustrated in Fig 4. In this research, the plant system is the transfer function of tank that determine through dynamic behaviour in section 3.1. The input of this system is the desired water level percentage determine by the user. Next, the water level is controlled using hybrid of SMC-GSPID control law, where the error signal is the difference between set point value and actual water level.

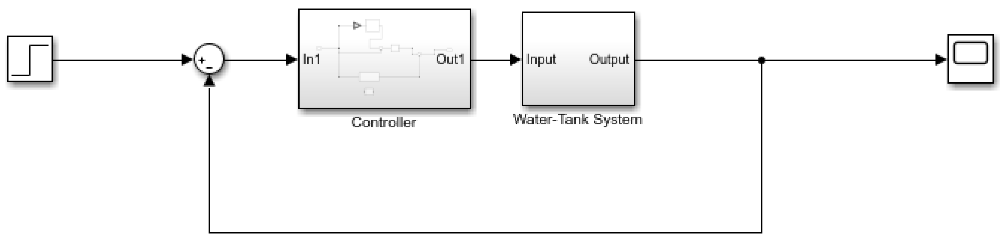

Fig. 4 *Water tank control system designed*

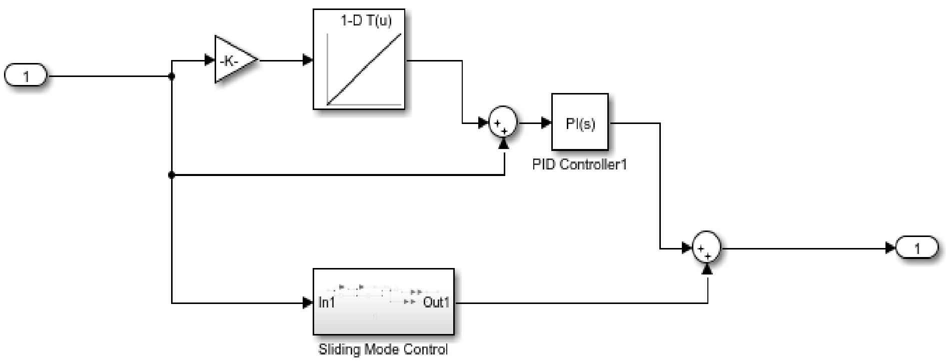

Fig. 5 *Hybrid SMC-GSPID controller block diagram*

4. Results

4.1 Experimental Design

The proposed hybrid SMC-GSPID is tested for water level control of three water levels. The three water level condition are 100%, 70% and 50%. The performance of the proposed SMC-GSPID is compared with water level controller using ZN PID, CC PID and TL PID. These three PID tuning methods are observed to be popularly adopted in previous works. Therefore, they are chosen for benchmarking with the proposed controller.

4.1.1 Ziegler Nichols

The ZN method uses the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop to express the dynamic characteristic of the process. The procedure often decides the final gain and period based on the actual process [41].

- To create a proportional controller, the integral and derivative modes of the feedback controllers are turned off.
- The proportional gain is increased in the automatic controller until the loop oscillates with constant amplitude.

- The period of oscillation is measured and recorded as T, the ultimate period, using a time recording of the controlled variable.

The proportional, integral, and derivative gains must be identified in order to optimize the system's rise time, settling time, overshoot, and steady-state error. The following table illustrates how raising each of the PID gains affects each of these system properties. Reducing the gains would have reverse of the effects depicted in the Table 1.

Table 1 *Tuning effect [41]*

Parameter	Rise Time	Overshoot	Settling Time	Steady State Error
Proportional (P)	Decrease	Increase	Small Change	Decrease
Integral (I)	Decrease	Increase	Increase	Eliminate
Derivative (D)	Small Change	Decrease	Decrease	Small Change

This method can be used if the plant doesn't have an integrator or dominant complex conjugate poles and the step response shows as an S-shaped curve. These step-response curves can be produced experimentally or using a dynamic simulation of the plant [42]. Table 2 describe the formula of Ziegler Nichols for closed system. The response is determined by two parameters: the delay time, L and the time constant, T. Fig 6 illustrates the S-shaped response curve. L represents time delay, K denotes process gain, and T represents total time period.

Table 2 *Ziegler Nichols formula [43]*

Controller Type	From step response		
	K_p	T_I	T_D
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	2L	L/2

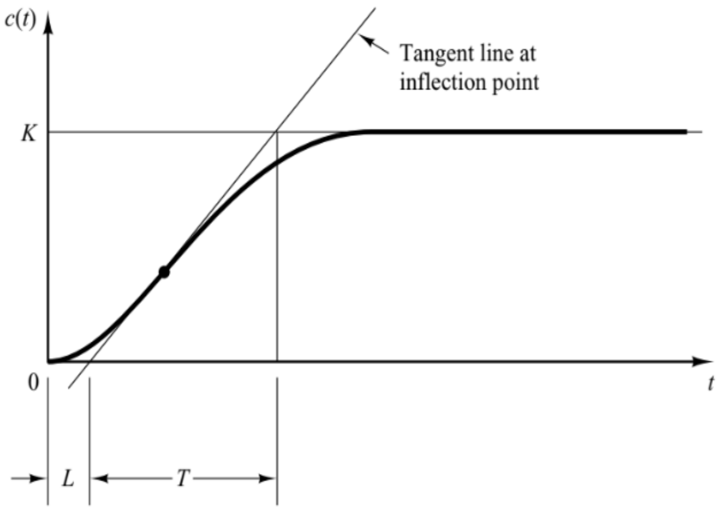

Fig. 6 *Ziegler Nichols formula [43]*

4.1.2 Cohen Coon

The CC method is also among the most robustly used strategies for tuning PID controllers. It is also referred to as a process reaction curve. Compared to the ZN tuning rules, the CC tuning rules are more applicable to a wider range of processes. When the dead time is less than twice the length of the time constant, the CC tuning rules perform well and can even be extended further if the process requires it. Furthermore, one major issue with CC parameters is that they are not very robust. There is a chance that a small adjustment to the process parameters will make the closed-loop system unstable and result in oscillatory closed loop behavior like ZN [44].

4.1.3 Tyreus Luyben

The TL procedure is very similar to the ZN method, except for the controller settings. Furthermore, this method only suggests settings for PI and PID controllers. Table 3 below shows the settings based on ultimate gain and period [45].

Table 3 *Tyreus Luyben formula [43]*

Controller Parameter	K_P	T_I	T_D
PI	$\frac{K_u}{3.2}$	$2.2P_u$	-
PID	$\frac{K_u}{3.2}$	$2.2P_u$	$\frac{P_u}{6.3}$

4.2 Findings and Discussion

Fig 7 illustrates the findings when the water level at 100%. The overshoot of TL is 34.1% and the CC method is 35.6%, ZN is 6.0% while SMC-GSPID is 2.9%. The hybrid SMC-GSPID, TL and CC have no steady state error, while ZN is 0.8%. In addition, the rise time for hybrid SMC-GSPID is 1.9 seconds, CC method 3.15 seconds and TL 3.52 seconds. From the results, ZN gives the longest rise time which is 5.8 seconds. The hybrid controller of SMC and PID is able to reach desired water level at short rise time, with minimum overshoot without steady state error. Thus, SMC-GSPID controller is able to reduce wastage of liquid and reach the set point with at shortest time.

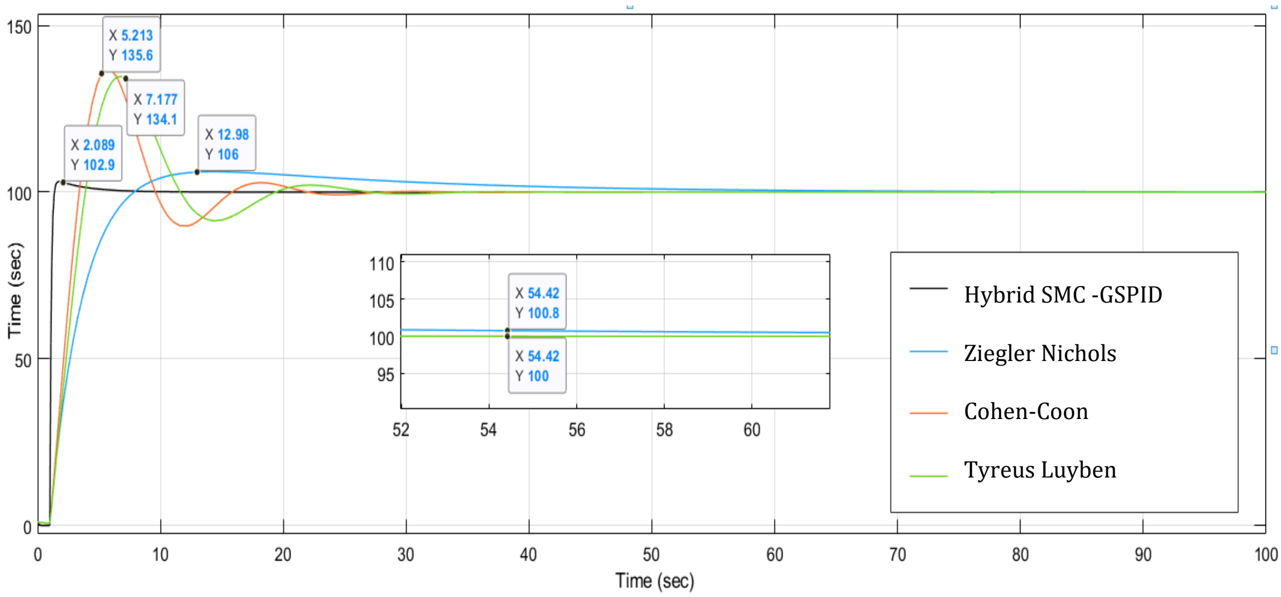

Fig. 7 *Performance of 100% water level*

Fig 8 illustrates the result when water level is set at 70%. The overshoot of TL is 34.26% and the CC method is 36.73%, ZN is 5.36%. Meanwhile, the overshoot of the proposed hybrid SMC-GSPID is the lowest at 2.89%. There are no steady error using hybrid controller SMC-GSPID, TL and CC method. The steady state error for ZN is 2.89. Furthermore, the rise time for hybrid SMC-GSPID is 1.9 seconds, 3.20 seconds for the CC method, and 3.60 seconds for TL. According to the results, ZN has the longest rise time of 5.8 seconds.

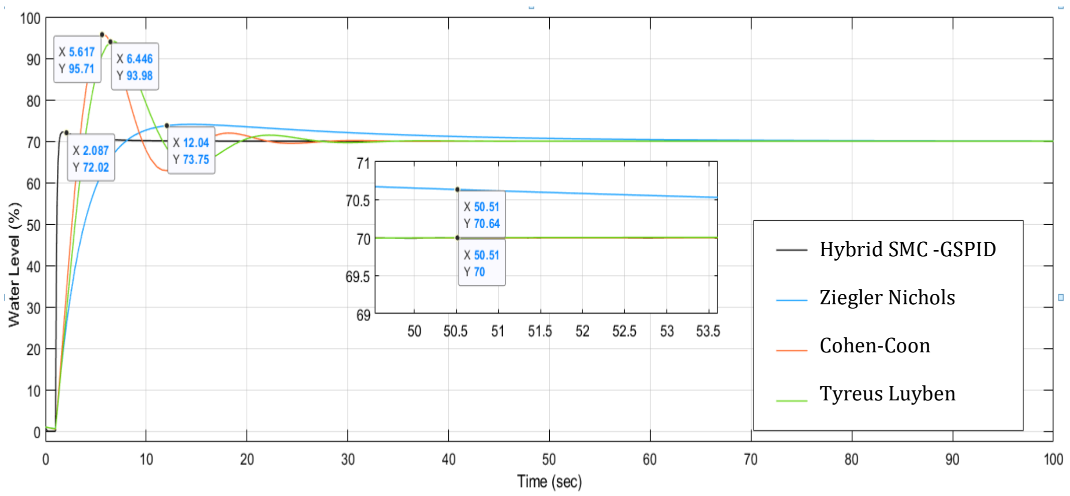

Fig. 8 *Performance of 70% water level*

Fig 9 illustrates the control result for water level at 50%. The overshoot of TL is 33.96% and the CC method is 36.38%, ZN is 5.08%. There are 3.12% overshoot for hybrid SMC-GSPID. Next, the ZN steady state error is 0.44%. There are no steady errors for hybrid SMC-GSPID, ZN, TL and CC method. Additionally, the rise times for CC method and TL are 4.20 seconds, and 3.6 seconds respectively. ZN provides the longest rise time, 5.8 seconds, and hybrid SMC-GSPID yield the shortest rise time with 1.60 second.

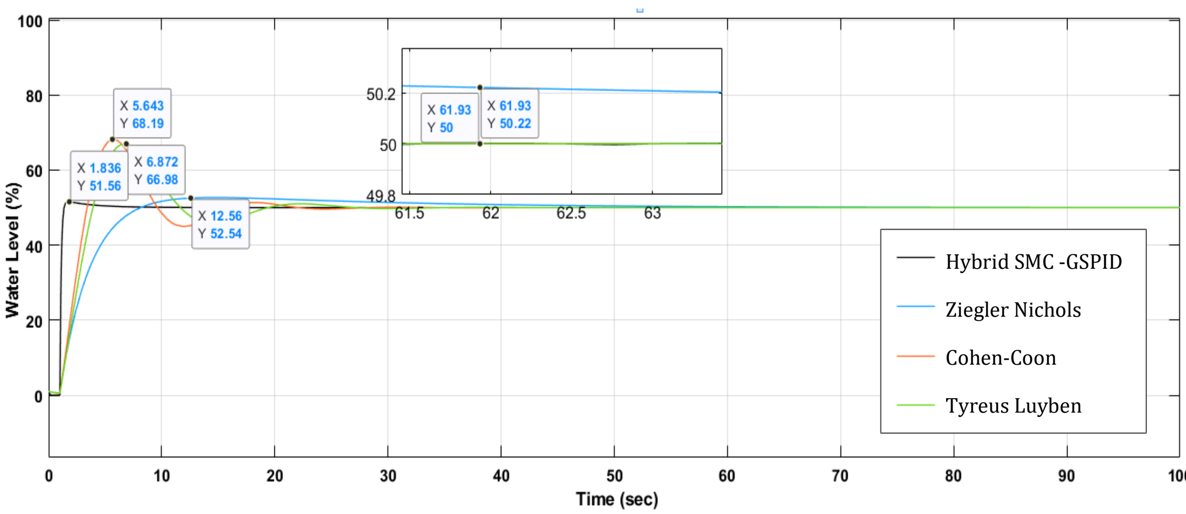

Fig. 9 *Performance of 50% water level*

From the simulation results, the proposed controller gives the smallest overshoot, with zero steady state error and reach the set point in shortest time for all water levels tested. This result confirms the stability of SMC-GSPID and it robustness against the disturbances and uncertainties. In addition, the GS acts as optimization element that contribute in good tracking performance for the controller.

5. Conclusions

This paper describes a hybrid SMC-GSPID controller for water tank system. The SMC-GSPID is used to maintain a required water level in a storage tank. This system can be used in water reserve tank for agriculture, chemical industry, or other sector. Based on the results, the proposed hybrid of SMC-GSPID is able to give the best performance with minimum overshoot and optimum rise time compared to PID using ZN, CC and TL tuning methods. This proves that the proposed controller able to controls the water levels, preventing overflow from the overhead tank and keeping the water level within the set margin. For future works, this research will be extended to consider parameters optimization using metaheuristics approaches such as particle swarm optimization, gravitational search algorithm, sine cosine algorithm and others for better system.

Acknowledgement

We would like to acknowledge the grants from Fisabilillah Research Development Grant Scheme (FRDGS) funded by the Jabatan Agihan Zakat (JAZ) Negeri Selangor (MMUE/210013) and Universiti Sains Islam Malaysia (USIM/MG/MMU-PPKMT-ZDA/FKAB/SEPADAN-S/70822).

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Anith Khairunnisa Ghazali, Nor Azlina Ab. Aziz;* ***data collection:*** *Anith Khairunnisa Ghazali;* ***analysis and interpretation of results:*** *Anith Khairunnisa Ghazali, Nor Azlina Ab. Aziz;* ***draft manuscript preparation:*** *Nor Azlina Ab. Aziz, Wan Zakiah Wan Ismail. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] B.N. Getu, Water level controlling system using PID controller, *Int. J. Appl. Eng. Res*. 11 (2016), pp. 11223–11227.
[2] A.M. Qahtan, T.N. Amer and A.M. Shaho, Simulation and Performance of Liquid level Controllers for Linear Tank, *J. Teknol*. 3 (2020), pp. 75–82.
[3] S. K*, Modelling and Controller Design for Non- Linear Two Tank Interacting System, I*nt. J. Innov. Technol. Explor. Eng*. 9 (2020), pp. 82–85.
[4] Y.-H. Lee, G.-G. Jin and M.-O. So, Level control of single water tank systems using Fuzzy-PID technique, *J. Korean Soc. Mar. Eng.* 38 (2014), pp. 550–556.
[5] M.N. Barabde and S.R. Danve, A Review on Water Quality Monitoring System, *Int. J. Eng. Res. Technol.* 06 (2015), pp. 1475–1479.
[6] C. Illes, G.N. Popa and I. Filip, Water level control system using PLC and wireless sensors, ICCC 2013 - IEEE 9th *Int. Conf. Comput. Cybern. Proc. (2013)*, pp. 195–199.
[7] H.M. Chen, Z.Y. Chen and J.P. Su, Design of a sliding mode controller for a water tank liquid level control system, *Int. J. Innov. Comput. Inf. Control* 4 (2008), pp. 3149–3159.
[8] C. Urrea and F. Páez, Design and comparison of strategies for level control in a nonlinear tank, *Processes 9* (2021).
[9] S. Krivić, M. Hujdur, A. Mrzić and S. Konjicija, Design and implementation of fuzzy controller on embedded computer for water level control, MIPRO 2012 - *35th Int. Conv. Inf. Commun. Technol. Electron. Microelectron. - Proc. (2012)*, pp. 1747–1751.
[10] C. Pu, J. Ren and J. Su, The sliding mode control of the drum water level based on extended state observer, *IEEE Access 7 (2019)*, pp. 135942–135948.
[11] R. Konwar, A Review on Sliding Mode Control: An Approach for Robust Control Process, *ADBU J. Electr. Electron. Eng. 1 (2017)*, pp. 6–13.
[12] T.H. Nguyen, T.T. Nguyen, H.N. Tran and J.W. Jeon, An Improved Sliding Mode Control Using Reduced-order PI Observer for PMSM system, *16th Int. Conf. Ubiquitous Inforation Mnagement Commun. (2022),* pp. 1–5.
[13] H.A.F. Mohamed, E.L. Lau, S.S. Yang and M. Moghavvemi, Fuzzy-SMC-PI Flux and Speed Control for Induction Motors, in 2008 *IEEE Conference on Robotics, Automation and Mechatronics, 2008*, pp. 325–330.
[14] L. Morales, J.S. Estrada, M. Herrera, A. Rosales, P. Leica and S. Gamboa, Hybrid Approaches-Based Sliding-Mode Control for pH Process Control, ACS Omega 7 (2022), pp. 45301–45313.
[15] H. Ahmed and A. Rajoriya, A Hybrid of Sliding Mode Control and Fuzzy Gain Scheduling PID Control using Fuzzy Supervisory Switched System for DC Motor Speed Control System, WSEAS *Trans. Syst. Control 12 (2017)*, pp. 106–113.
[16] D.L. Zhang, Y.P. Chen, J.M. Xie, W. Ai and C.M. Yuan, A Hybrid Control Method of Sliding Mode and PID Controllers Based on Adaptive Controlled Switching Portion *, in *Proceedings of the 29th Chinese Control Conference, 2010*, pp. 439–445.
[17] P.V.G.K. Rao, M. V. Subramanyam and K. Satyaprasad, Study on PID controller design and performance based on tuning techniques, *2014 Int. Conf. Control. Instrumentation, Commun. Comput. Technol. ICCICCT 2014 (2014)*, pp. 1411–1417.
[18] G. Jialiang, L. Zhimin and T. Huaijiang, Research on Self-tuning PID Control Strategy Based on BP Neural Network, *2011 Int. Conf. Electron. Optoelectron. (ICEOE 2011) (2011),* pp. 6–11.
[19] C. Vinothkumar and C. Esakkiappan, Level control of nonlinear hopper tank process in pharmaceutical industry using Ziegler Nicholas and Cohen Coon tuning techniques, *Int. J. Innov. Technol. Explor. Eng. 8 (2019),* pp. 4093–4096.

[20] S.M. Kesavan, T.V.N. Padmesh and C.W. Shyan, Controller tuning for nonlinear hopper process tank – A real time analysis, J. *Eng. Sci. Technol. 9 (2014),* pp. 59–67.

[21] C.A. Bojan-Dragos, M.B. Radac, R.E. Precup, E.L. Hedrea, A.I. Szedlak-Stinean and S. Preitl, Gain-scheduling position control approaches for electromagnetic actuated clutch systems, *ICINCO 2018 - Proc. 15th Int. Conf. Informatics Control. Autom. Robot. 2 (2018)*, pp. 411–418.

[22] S.C. Pratama, E. Susanto and A.S. Wibowo, Design and implementation of water level control using gain scheduling PID back calculation integrator Anti Windup, ICCEREC 2016 - I*nt. Conf. Control. Electron. Renew. Energy, Commun. 2016, Conf. Proc. (2017),* pp. 101–104.

[23] S. Merlin and K. Prabhu, Fuzzy Gain Scheduled PI Controller for a Two Tank Conical Interacting Level System, *Int. Res. J. Eng. Technol. 6 (2015)*, pp. 2587–2594.

[24] M.T. Alam, P. Charan, Q. Alam and S. Purwar, Sliding Mode Control of Coupled Tanks System: Theory and an Application, *Int. J. Emerg. Technol. Adv. Eng. 3 (2013)*, pp. 650–656.

[25] T. Toms and H. D, Mode Controller for a Coupled Tank System, *Int. J. Eng. Res. Technol. 3 (2014)*, pp. 151–154.

[26] D. Chiriţə, A. Florescu, B.C. Florea, R. Ene and D.A. Stoichescu, Liquid level control for industrial three tanks system based on sliding mode control, *Rev. Roum. des Sci. Tech. Ser. Electrotech. Energ. 60 (2015)*, pp. 437–446.

[27] L. Baofeng and Z. Guoxiang, Simulation and Research of Control-System for PMSM Based on Sliding Mode Control, 2012 *Int. Conf. Med. Phys. Biomed. Eng. 33 (2012),* pp. 1280–1285.

[28] G.E.M. Abro, S.A.B.M. Zulkifli, V.S. Asirvadam and Z.A. Ali, Model-free-based single-dimension fuzzy smc design for underactuated quadrotor uav, *Actuators 10 (2021).*

[29] M.T. Vu, K.A. Alattas, Y. Bouteraa, R. Rahmani, A. Fekih, S. Mobayen et al., Optimized Fuzzy Enhanced Robust Control Design for a Stewart Parallel Robot, Mathematics 10 (2022), pp. 1–36.

[30] M. Dong and B. Guo, Research on Control Algorithm of Water-tank Water Level Control System, *Int. J. Control Autom. 9 (2016),* pp. 1–10.

[31] P.U. Palkar, P.S. Vikhe, C.B. Kadu and B. J, Design of Tank Level system using Gain Scheduling Controller, 5 (2018).

[32] H. Mamur, I. Atacak, F. Korkmaz and B. M.R.A., Modelling and Application of a Computer-Controlled Liquid Level Tank System, *Comput. Sci. Inf. Technol. (CS IT) (2017),* pp. 97–106.

[33] Y. Pimpale and B. Parvat, Design of Sliding Mode Control for Nonlinear Uncertain System, *Int. J. Adv. Res. Innov. Ideas Educ. 4 (2018)*, pp. 331–336.

[34] K.S. Venkatesh, Sliding Mode Controller Design for Three Tank System, Int. J. *Res. Eng. Sci. Manag. 3 (2020),* pp. 565–569.

[35] F. Alhaj Omar, Performance Comparison of Pid Controller and Fuzzy Logic Controller for Water Level Control with Applying Time Delay, *Konya J. Eng. Sci. 9 (2021)*, pp. 858–871.

[36] C.S. Kang, C.H. Hyun, Y.T. Kim, J. Baek and M. Park, A design of equivalent PID structure control using Fuzzy gain scheduling, 2013 10th Int. Conf. Ubiquitous Robot. Ambient Intell. *URAI 2013 (2013),* pp. 354–356.

[37] A. Visioli, Research trends for PID controllers, *Acta Polytech. 52 (2012),* pp. 144–150.

[38] A.A. Zaher, Design of Model-Based Gain Scheduling Controllers for Nonlinear Systems, J. *Phys. Conf. Ser. 1141 (2018).*

[39] V.K. Jadhav and S. N.Gawale, Gain Scheduling of PID Controller for Level Control System & Comparative Analysis of PID Controllers, *Int. J. Adv. Res. Electr. Electron. Instrum. Eng. 7 (2018),* pp. 459–464.

[40] A. Rodriguez-Martinez and R. Garduno-Ramirez, Comparative analysis of PI controller gain-scheduling through fuzzy systems, CERMA 2009 - *Electron. Robot. Automot. Mech. Conf. (2009),* pp. 366–371.

[41] S. Das, A. Chakraborty, J.K. Ray, S. Bhattacharjee and B. Neogi, Study on Different Tuning Approach with Incorporation of Simulation Aspect for Z-N (Ziegler-Nichols) Rules, *Int. J. Sci. Res. Publ. 2 (2012),* pp. 1–5.

[42] T.T. Hlaing, Simulation of Ziegler-Nichols PID Tuning for Position Control of DC Servo Motor, *Int. J. Sci. Res. Publ. 9 (2019)*, pp. p9184.

[43] K. Ogata, Modern Control Engineering, FIFTHPEARSON, United States of America, 2009.

[44] A.K. Mehta and R. Swarnalatha, Performance evaluation of conventional pid control tuning techniques for a first order plus dead time blending process, *J. Eng. Sci. Technol. 13 (2018),* pp. 3593–3609.

[45] T. Marismurugan, G. Revathy and E. Sathish, Comparative Study of Performance in Three Mode Controller Tuning, *J. Appl. Sci. Comput. 5 (2018),* pp. 1772–1777.