Pertanika J. Sci. & Technol. 25 (S): 275 - 284 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Optimising PID Controller using Slope Variation Method for Positioning Radio Telescope

N. Mohamad Zaber[1]*, A. J. Ishak[1], A. Che Soh[1], M. K. Hasan[1] and A. N. Ishak[2]

[1]*Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*

[2]*National Space Agency (ANGKASA) Lot 2233, Jln Turi, Sg. Lang, Banting, Selangor, Malaysia*

ABSTRACT

Radio telescope is an application that requires a precise position control as it should point to the exact coordinate so that it could receive the desired signal. The main idea of this paper is to optimise the PID controller by introducing slope variation method in order to control the position of a radio telescope. This proposed method is also validated with the presence of disturbance, such as wind gust disturbance with different speed amplitude. The results indicate that the proposed optimisation method has a better result with no overshoot and able to attenuate wind gust disturbance when compared with conventional PID controller.

Keywords: PID optimisation, position control, radio telescope

INTRODUCTION

For a large radio telescope, it is essential it receives the intended signal while keeping its position accuracy. The challenges of maintaining its accuracy is increased when the radio telescope exposed to disturbances and nonlinearities such as wind disturbance, saturation, backlash and many more. In order to sustain the accuracy, different control method and strategies are used.

Cho et al., had utilised H∞ using step tracking algorithm to control the antenna system (Cho et al., 2003) where this method satisfied the requirement of the system. Referring to (Sahoo and Roy 2014; Garcia-Sanz et al., 2012), QFT method had been used, where Suresh Kumar Sahoo et al. mentioned that the performance of the controller is satisfactory and meet the stability specifications with overshoot of 2.24% and very low steady state error. It takes into account the plant uncertainty in designing the

ARTICLE INFO

Article history:
Received: 24 August 2016
Accepted: 02 December 2016

E-mail addresses:
nsaida.mzaber@gmail.com (N. Mohamad Zaber),
asnorji@upm.edu.my (A. J. Ishak),
azuracs@upm.edu.my (A. Che Soh),
khair@upm.edu.my (M. K. Hassan),
asnor@angkasa.gov.my (A. N. Ishak)
*Corresponding Author

ISSN: 0128-7680

QFT controller. On the other hand, Garcia-Sanz et al., had considered saturation constraints in the simplified rigid body model of an existing extra-large radio telescope. The robustness of the designed QFT had been able to overcome the disturbance even in the influence of saturation nonlinearity. However, H∞ and QFT methods require a lot of mathematical formulation and understanding and hence become complicated.

Fuzzy logic controller then emerged as this method express mathematical equation based on phrases and thus make it understandable. Fuzzy logic has been used widely in controlling the radio telescope such as by (Okumus et al., 2012; 2013). Okumus et al., had employed several fuzzy membership functions such as triangle, trapezoid, Gaussian, bell and Cauchy and compared the performance between them. The best membership function was then used in self-tuning fuzzy logic controller where it showed an improvement in terms of overshoot and rise time. Nevertheless, expert knowledge of the system is required prior to implementing fuzzy logic controller so that fuzzy rules and its range can be properly set. Not only that, the process of designing fuzzy logic controller is still depending on trial-and-observation practice (Chen et al., 1993). Somehow, this condition caused difficulties in determine fuzzy rules and its range.

On contrary, PID controller has been used since decades ago due to its simplicity, easy to understand and implement and also able to control wide range of system applications (Qiu et al., 2014; Rahmani et al., 2012; Namazov, 2010; Yousef, 2012; Qiu et al., 2014). It is one of the earlier control methods that still commonly used now. PID controller work by adjusting and tuning its parameters' value until the desired output is met. However, this process consumes time and requires a lot of adjusting and tuning process. Thus, the purpose of this paper is to optimize the PID controller by introducing slope variation method and improve the performance of the controller including reduce the time consumed during tuning process.

MODELLING OF RADIO TELESCOPE

Radio telescope consists of two parts:

- DC servo motor
- Parabolic antenna dish (load)

In this section, the procedure in obtaining radio telescope model is presented.

DC Servo Motor

Servo motor is a type of motor for operation involving position control as well as speed control. Input of this radio telescope is obtained from potentiometer which then converted to voltage and fed into a dc servo motor. Torque,T_m, developed by servo motor will rotate the antenna dish with desired speed, ω_m.. The motor is driven only when there is difference between input and output. The larger the value, the greater the motor input voltage, and the faster motor turned (Nise, 2011). DC servo motor is modelled by converting the motor equation into Laplace transfer function.

Parabolic Antenna Dish (Load)

In this paper, the load is a parabolic antenna dish with diameter of 18 m. This dish is mounted on the servo motor. Generally, a radio telescope is made of two axes; azimuth (rotate side-to-side direction) and elevation (moving up-down direction). In this paper the azimuth axis is studied. The angle of rotation for azimuth axis is between 0 - 360°. Figure 1 below illustrates the azimuth and elevation axis of a radio telescope as well as the schematic diagram of dc servo motor.

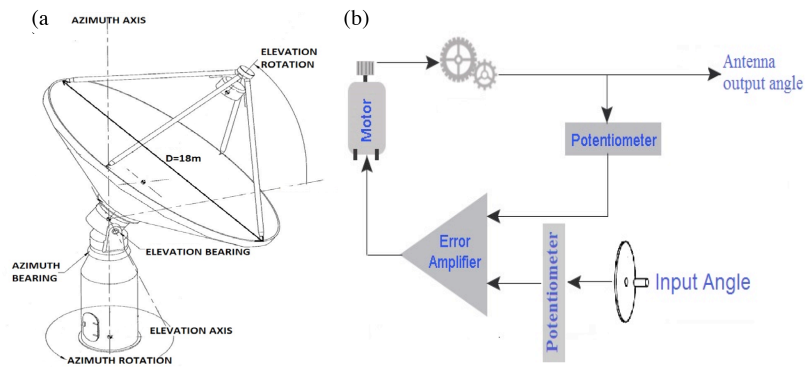

Figure 1. (a) Radio telescope; (b) Schematic diagram of DC servo motor within radio telescope system

METHODOLOGY

PID controller was used in this project where it attempts to minimize the error generated by the system. The structure of PID controller is as Figure 2 below. K_p, K_i and K_d values are tuned to achieve the radio telescope performance criteria, in terms of overshoot, rise time, settling time and steady state error. In this paper, Ziegler-Nichols (ZN) heuristic method and the proposed PID optimization using slope variation method are implemented. Designed controller is validated by introducing wind gust disturbance into the system.

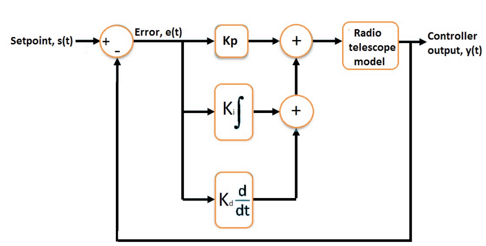

Figure 2. PID controller structure

ZN Parameter Tuning

PID controller is tuned using ZN method where only K_p value is varied while others are set to zero. K_p value is tuned until it reaches natural frequency i.e. constant oscillation. Then K_i and K_d values obtained by applying equation (1) where T_{int}, T_{der} are integral and derivative time constant.

$$C(s) = K_P\left(1 + \frac{1}{T_{\text{int}}s} + \frac{T_{der}s}{1 + \tau_{der}s}\right) \quad (1)$$

Optimising PID Controller

The proposed optimisation of PID controller is done by considering the slope of the output response whenever PID parameters are varied as shown in Figure 3. The slope value is observed once output reach set point. This observation is important as it will affect overshoot and steady state error values. Eq. (2) below express the slope equation of the output response where $y(t_h)$ is the highest output response.

$$Slope, sl_1 = \frac{y(t_h) - y(t_{h-1})}{t}; slope, sl_2 = \frac{y(t_{h+1}) - y(t_h)}{t} \quad (2)$$

This optimisation is done following steps below:

- K_p value is tuned until the set point reach. The highest output response is determined and slope values are calculated.
- K_d is increased while keeping the attention to the slope value until the acceptable overshoot is met.
- K_i is tuned in eliminating the steady state error by ensuring the slope values are always close to zero.

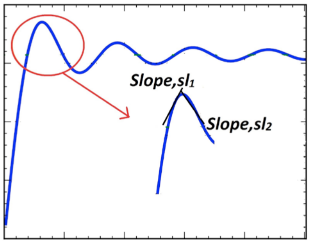

Figure 3. Slope at maximum response

Wind Model

Wind disturbance is one of the external factors that could affect the performance of the radio telescope by deviating it from desired position (Gawronski, 2008). Generally, there are two types of wind loads that act towards the radio telescope antenna dish; namely steady-state and dynamic (gust) load (Gawronski, 2004). In this paper, only dynamic load is considered. This wind gust disturbance model is presented in the form of torque, T_g, act upon radio telescope drive, T_m, in which it gives increment to the total torque, T, as shown in Figure 3. Wind gust is generated from white noise of unit standard deviation that being formed from Davenport filter with a constant value, k_w.

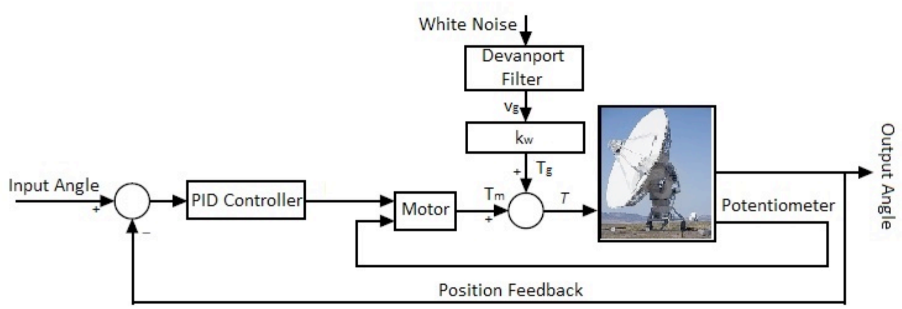

Figure 4. Wind disturbance acting on the antenna dish

The wind torque, T_g, is actually acquired from and related to the velocity gust value, v_g, where it is a component of wind velocity, vw, and steady state wind velocity, v_s, as per equation (3). The wind gust component, v_g, is a random process with zero mean together with a Davenport spectrum. From here, the T_w is obtained by linearizing equation (4) i.e. wind quadratic law for torque T and steady state wind, v_s, which produce equation (5).

$$v_w = v_s + v_g \tag{3}$$

$$Torque, T = k_w {v_s}^2 \tag{4}$$

$$T_g = 2k_w v_s v_g \tag{5}$$

RESULTS AND DISCUSSION

The output of the simulation is presented and discussed in this section. Tuning PID parameters using ZN method somehow is tedious and time consuming. After tuning the K_p values, it turned out that the response cannot produce constant oscillation as shown in Figure 4 (a-d). Thus, the PID parameters are then set using trial-and-error method where K_p value is choose by referring to the ZN output that gives better result compared to other values. Thus, the obtained parameters value is K_p=20, K_i=0.5 and K_d=3.

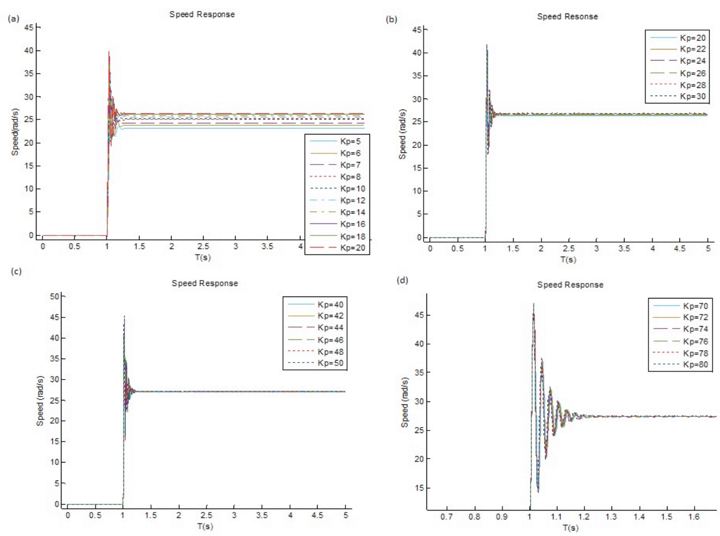

Figure 5. Tuning PID parameters using ZN method

Speed Loop

This speed loop shows the speed response for both PID and optimised PID using slope variation method without load. PID-slope variation method showed a more accurate output and faster response where it recorded a rise time of 0.09s when compared to PID with 0.3s.

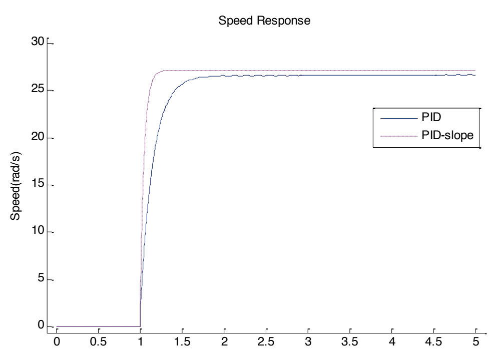

Figure 6. Comparison of speed response between PID and PID-slope variation method

Position Loop

Figure 7 shows that the optimisation of PID using slope variation method is able to reach set point without overshoot. The analysis of the output is as Table 1.

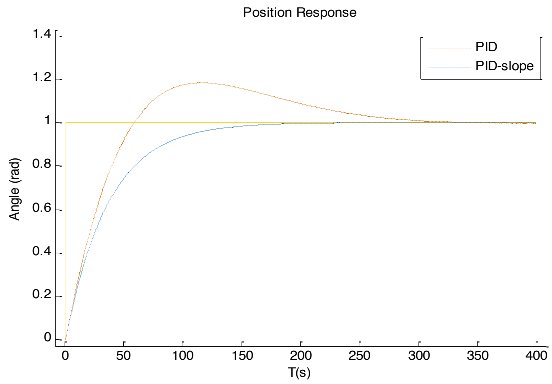

Figure 7. Position response

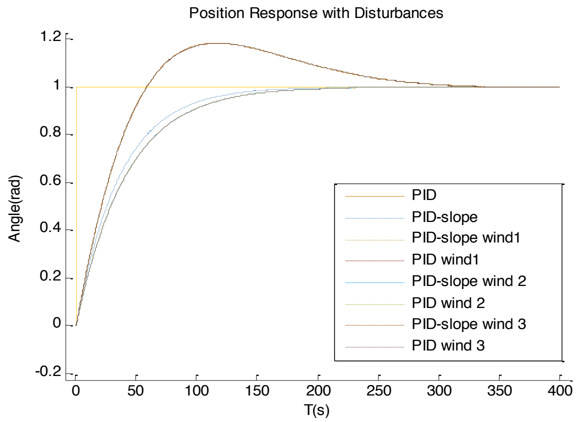

Figure 8. Position response with presence of wind gust disturbance

Referring to Figure 8, when wind gust disturbance with different speed amplitude (2 (wind 1),4 (wind 2) and 6 (wind 3)) introduced to the system, PID-slope variation took a bit longer time i.e. difference of about 11.32s to reach 90% of the output (for all speed) compared when there is no disturbance. This situation is common as it has to face the resistance of the wind. On the other hand, conventional PID controller cannot attenuate wind gust disturbance and produce overshoot to the system, similar as without disturbance.

Table 1
Analysis of output response of radio telescope

	Without disturbance		Wind disturbance	
	PID	PID-slope variation	PID	PID-slope variation
Rise time, Tr (s)	43.5	79.3	43.5	91.64
% Overshoot	18.4	0	18.4	0

CONCLUSION

This paper presents the analysis of positioning radio telescope positioning by optimizing PID controller using slope variation method and conventional PID controller. Results showed that the proposed optimization method produces better results and being able to attenuate wind gust disturbances.. It also has a tolerable rise time for a 18m radio telescope.

ACKNOWLEDGEMENT

This research was supported by Agensi Angkasa Negara, Ministry of Science, Technology and Innovation (MOSTI) and research grant Universiti Putra Malaysia.

REFERENCES

Chen, C. L., & Chen, P. C. (1993). Analysis and design of fuzzy control system. *Fuzzy Sets and Systems, 57*(2), 125-140.

Cho, C. H., Lee, S. H., Kwon, T. Y., & Lee, C. (2003). Antenna control system using step tracking algorithm with H∞ controller. *International Journal of Control, Automation and Systems, 1*(1), 83-92.

Garcia-Sanz, M., Ranka, T., & Joshi, B. C. (2012, July). High-performance switching QFT control for large radio telescopes with saturation constraints. In *Aerospace and Electronics Conference (NAECON), 2012 IEEE National* (pp. 84-91). IEEE.

Gawronski, W. (2004). Modeling wind-gust disturbances for the analysis of antenna pointing accuracy. IEEE Antennas and *Propagation Magazine, 1*(46), 50-58.

Gawronski, W. (2008). *Modeling and control of antennas and telescopes*. Springer book.

Namazov, M., & Basturk, O. (2010). DC motor position control using fuzzy proportional-derivative controllers with different defuzzification methods. *Turkish Journal of Fuzzy Systems, 1*(1), 36-54.

Nise, N. S. (2011). *Control System Engineering* (6th Ed). John Wiley & Sons, Inc.

Okumus, H. I., Sahin, E., & Akyazi, O. (2012). Antenna azimuth position control with classical PID and fuzzy logic controllers. In *2012 International Symposium on Innovations in Intelligent Systems and Applications* (pp. 1-5).

Okumus, H. İ., Sahin, E., & Akyazi, O. (2013, November). Antenna azimuth position control with fuzzy logic and self-tuning fuzzy logic controllers. In *Electrical and Electronics Engineering (ELECO), 2013 8th International Conference on* (pp. 477-481). IEEE.

Qiu, D., Sun, M., Wang, Z., Wang, Y., & Chen, Z. (2014). Practical wind-disturbance rejection for large deep space observatory antenna. *IEEE Transactions on Control Systems Technology, 22*(5), 1983-1990.

Rahmani, R., Mahmodian, M. S., Mekhilef, S., & Shojaei, A. A. (2012, December). Fuzzy logic controller optimized by particle swarm optimization for DC motor speed control. In *Research and Development (SCOReD), 2012 IEEE Student Conference on* (pp. 109-113). IEEE.

Sahoo, S. K., & Roy, B. K. (2014, February). Antenna azimuth position control using Quantitative feedback theory (QFT). In *Information Communication and Embedded Systems (ICICES), 2014 International Conference on* (pp. 1-6). IEEE.

Yousef, A. M. (2012). Experimental set up verification of servo DC motor position control based on integral sliding mode approach. *WSEAS Transactions on Systems and Control, 7*(3), 87- 96.