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OPTIMAL PID TUNING BASED ON SLOPE VARIATION APPROACH FOR POSITION CONTROL OF RADIO TELESCOPE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Radio telescope is an astronomical instrument used to study radio astronomy activities including observing the celestial activities such as sun, galaxies, pulsars, stars, monitor the submillimeter wavelength and many more. Radio waves received are very weak and of low intensity. Due to this, the signals are easily distracted by interference. To resolve this, antenna dish has been increased in size which gives a larger collecting areas and increased its operating frequency. However, another difficulty arises and create challenges in controlling and positioning the radio telescope. On top of that, the antenna is also exposed to disturbances namely wind disturbance that makes the control process even worse. In view of that, with the aim to have an accurate position output, it is essential to employ a precise and robust controller.

This research utilised a PID controller for position control of the radio telescope. However, PID faces big challenges in determining its parameters values. It suffers unsatisfactory performance such as time consuming, tedious work, lack of precision and robustness. Thus, an optimal approach is proposed to obtain the parameters by using slope variation method. Radio telescope was modelled based on real telescope with 18-m diameter. A Ziegler Nichols (ZN) and ZN+ were executed during control process. These methods were chosen since they are one of the widely use method for tuning PID. Then the slope variation approach implemented to the radio telescope model. The control methods were run in speed loop followed by position loop. Performance of the proposed approach was compared with ZN and ZN+ methods. The results showed that the slope variation approach provide promising results in terms of precision and percentage of overshoot with 0.001° position accuracy and zero overshoot. On the other hand, ZN+ method obtained only 0.034° of position accuracy and 5% overshoot.

Realising radio telescope continually exposed to wind gust disturbance, the wind gust was modelled together with the radio telescope model. The wind gust is designed based on the wind speed in Malaysia where it differs according to the seasons. Malaysian Meteorological Department (MET) recorded the slowest wind speed is 10 knots while the highest wind speed is 81.06 knots. Thus, the proposed controller is tested to control the radio telescope position with presence of wind gust disturbance as mentioned above values. The conducted tests showed the position accuracy employing slope variation approach reduce to 0.0012˚ but still in the expected range while ZN+ method 0.053˚.

The PID controller using slope variation approach has successfully control the position of radio telescope and meets the designed specifications. Not only that, the proposed approach also able to overcome the highest possible wind gust disturbance with small deviation and satisfactory position accuracy.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENALAAN OPTIMUM PID BERDASARKAN PENDEKATAN VARIASI KECERUNAN BAGI KAWALAN KEDUDUKAN TELESKOP RADIO

Oleh

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Teleskop radio merupakan peralatan astronomi yang digunakan untuk mengkaji aktiviti astronomi radio termasuk pemerhatian aktiviti di angkasa seperti matahari, galaksi, pulsar, bintang, pemerhatian gelombang submilimeter dan banyak lagi. Gelombang radio yang diterima adalah sangat lemah dan dalam intensiti yang rendah. Disebabkan itu, isyarat lebih mudah terganggu oleh gangguan. Untuk menyelesaikan masalah ini, saiz piring antenna telah meningkat dimana ia memberi penambahan kepada kawasan mengumpul isyarat dan peningkatan frekuensi operasi. Walau bagaimanapun, kesukaran lain pula yang timbul dan mencipta cabaran baru dalam mengawal dan memposisikan teleskop radio. Selain itu, antena juga terdedah kepada gangguan iaitu gangguan angin yang mana ia menyulitkan lagi proses kawalan. Memandangkan itu, dengan tujuan untuk mendapatkan keputusan kedudukan yang tepat, ianya sangat penting untuk menggunakan kawalan yang lebih tepat dan mantap.

Kajian ini menggunakan kawalan PID untuk mengawal kedudukan teleskop radio. Walau bagaimanapun, PID berhadapan cabaran besar dalam menentukan nilai parameter-parameternya. Ia mengalami prestasi yang tidak memuaskan seperti memakan masa yang lama, kerja yang merumitkan, kurang ketepatan dan kurang mantap. Oleh itu, satu pendekatan yang optimum dicadangkan dalam memperoleh parameter-parameter dengan menggunakan kaedah variasi kecerunan. Teleskop radio telah dimodelkan berdasarkan teleskop radio yang sebenar dengan diameter piring 18-m. Ziegler Nichols dan ZN+ telah digunakan semasa proses kawalan. Kaedah-kaedah ini telah dipilih memandangkan ia merupakan kaedah yang digunakan secara meluas dalam penalaan PID. Kemudian, kaedah variasi kecerunan dilaksanakan pada model teleskop radio. Kaedah kawalan ini dijalankan dalam gelung kelajuan diikuti gelung posisi. Prestasi kaedah cadangan variasi kecerunan dibandingkan dengan kaedah ZN dan ZN+. Keputusan menunjukkan pendekatan variasi kecerunan memberikan hasil yang meyakinkan dari segi ketepatan dan peratusan lanjakan dengan 0.001° ketepatan posisi

dan tiada lanjakan. Sebaliknya, kaedah ZN+ hanya memperoleh ketepatan posisi sebanyak 0.034˚ dan lanjakan sebanyak 5%.

Menyedari teleskop radio berterusan terdedah kepada gangguan angin yang mendadak, model kepada gangguan angin yang mendadak direka berserta model teleskop radio. Model angin yang mendadak direka berdasarkan kelajuan angin di Malaysia di mana ia berbeza mengikut musim. Jabatan Meteorologi Malaysia mencatatkan kelajuan angin terendah adalah 10 knots manakala kelajuan angin tertinggi sebanyak 81.06 knots. Dengan itu, kawalan yang dicadangkan diuji untuk mengawal posisi teleskop radio dengan kehadiran gangguan angin berkelajuan seperti disebut di atas. Ujian yang dijalakankan menunjukkan ketepatan kedudukan menggunakan variasi kecerunan berkurang kepada 0.0012˚, tetapi masih di dalam julat yang dijangka, manakala kaedah ZN+ mencatatkan 0.053˚.

Kawalan PID menggunakan pendakatan yang dicadangkan, variasi kecerunan telah berjaya mengawal kedudukan teleskop radio dan mencapai spesifikasi reka bentuk. Bukan itu sahaja, bahkan pendekatan yang dicadangkan turut berjaya mengatasi kebarangkalian kelajuan angin yang mendadak dengan sisihan yang kecil dan ketepatan kedudukan yang memuaskan.

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I certify that a Thesis Examination Committee has met on 27 December 2016 to conduct the final examination of Nursaida Mohamad Zaber on her thesis entitled "Optimal PID Tuning Based on Slope Variation Approach for Position Control of Radio Telescope" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science

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LIST OF ABBREVIATIONS

PID	Proportional Integral derivative
ZN	Ziegler Nichols
QFT	Quantitative Feedback Theory
LQR	Linear Quadratic Regulator
LQG	Linear Quadratic Gaussian
DSN	Deep Space Network
DC	Direct Current
QO	Quadratic Optimal
TISO	Two Input Single Output
GMRT	Giant Meterwave Radio Telescope
BLDC	Brushless Direct Current
emf	Electromotive force
D	Davenport filter

LIST OF SYMBOLS

V_{in}	Input voltage
V_{out}	Output voltage
R_a	Armature resistance
L_a	Armature inductance
V_e	Back emf voltage
I_a	Armature current
V_m	Motor armature voltage
K_e	Back emf constant
T_m	Motor torque
k_m	Motor constant
J_m	Motor inertia
θ_m	Motor angle
N	Motor gear ratio
ω_m	Motor speed
T_a	Load antenna torque
θ_a	Antenna angle
J_a	Antenna inertia
K_a	Antenna constant
K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
T_i	Integral action time
T_d	Rate time
$u(t)$	Input signal
$e(t)$	Error
K_c	Critical gain
T_c	Critical period
s	s-domain in Laplace transform
v	Wind speed
v_s	Static wind velocity
v_{gust}	Wind gust velocity
T_g	Wind gust torque
k_g	Wind gust scaling factor
T_w	Wind quadratic law for torque
k_T	Terrain profile constant
σ_t	Dimensionless torque coefficient
α_p	Static air density
A	Antenna parabolic dish frontal area

T	Total torque
T_r	Rise time

CHAPTER 1

INTRODUCTION

1.1 Background

Radio telescope is an instrument that is used in radio astronomy field. It is used to capture electromagnetic waves being emitted by object in the outer space such as the sun, moon, stars, galaxies and many more [1]. Thus, radio astronomy activities require the radio telescope to be pointed to the desired location or position precisely. It is important to do so in order to prevent signal lost as the signal is remarkably weak once it reached the earth [2].

Several effort has been carried out to overcome this situation such as increase the operating frequencies as well as design a larger antenna dish which indicate larger collecting area [3], [4]. At the moment, radio technology is allowed to operate at frequency above 1 THz which astonishingly high and it should be implemented above terrestrial atmosphere which become much far away. This situation then mandates for an effective control and tremendously larger dish and pointing accuracy [5]. Moreover, a radio telescope is also facing rapid changes where current largest antenna dish built is 500 m in China [4]. These introduce another challenges to the control system in order to meet the desired position since larger dish diameter denotes a more sensitive system that need a precise output.

As per aforementioned, it is desirable to ensure the radio telescope is able to meet the needed position even in the influence of physical (hardware) deformation or external disturbances by employing good controller. For instance, performance of radio telescope may be affected by physical wearing, backlash, wind gust disturbance and many more. Currently, various controller is available in the industry as control system is growing rapidly. In radio telescope application, few control methods are available such as $H\infty$ controller [6], [7], Linear Quadratic Gaussian (LQG) controller [1], fuzzy logic controller [8]–[10] Quantitative Feedback Theory (QFT) controller [11], fuzzy-PID controller [12], adaptive control [13], PID controller and many more. Amongst mentioned controller, PID is the most popular and widely used in various industry and applications including in this area [14].

The fact that PID is among pioneer in control systems, up till now it is still relevant and attractive due to its simplicity and easy to understand [15]. PID operates by manipulating or tuning its parameters values and able to produce a promising result. The Ziegler Nichols (ZN) method is one of the most well-known tuning technique available. Though, ZN occasionally has difficulty and incompatible to implement that causes practitioners resort to trial and error technique [16].
In this research, the main interest is to model the radio telescope with disturbance that could mimic the behaviour of real radio telescope in simulation and design a PID controller with proposed slope variation approach so that it could facilitate the demand for having a precise controller even in the existence of external disturbance.

1.2 Statement of Problem

Radio signals from space are weak and they are easily affected by interference from earth based radio signal; for instance, from transmitters for ground satellite. Due to that, radio telescope commonly located in the remote regions [17]. With that, radio telescope is exposed to several external disturbances and most prominently is the wind gust disturbance. On top of that, wind gust could occur when wind speed reaches its peak value of at least 16 knots. This condition could deteriorate the performance of the system where it could reduce the accuracy of the antenna position [18]. This is because, normally the higher wind speed generates the worst situation because it yields a greater torque per unit error [19]. On the other hand, rapid growth in this area has contributed to a higher frequency used. The changes in frequency and environment volatility have effect on both hardware and control algorithm as well as the physical state of the antenna structure such as choice for suitable motor, control method and many more [20].

In view of that, a satisfying controller is indeed in need. PID controller is chosen to be used in this research because it still possess a significant favourites where it dominates about 90% of all control loops choice for control engineers [21] and it has already been used in controlling radio telescope. However, its parameters need to be adjusted in order to meet the predicted position. The parameters tuning process remains as a challenge for engineers as it directly affects the effectiveness of PID controller. As the most widely used technique, ZN consume a huge amount of time and devote effort [21] [22]; as it is a tedious process. On top of that, it also sometimes may not be suitable to be implemented to certain system plant [16] and always force the system to its instability region [22]. Numerous research has been done to tackle this problem and come out with several solutions such as Tyreus-Luyben method, Cohen-Coon method and good gain method. Nevertheless, these methods are still practices trial and error method, aggressive tuning, requires mathematical equation and only suitable for first order process. In addition to that, gradient descent method also emerges in tuning PID parameter. However, it uses iteration for tuning purposes which takes time to converge and its step size yet to have appropriate direction.

Thus, a controller that offers simple tuning approach with fast response, sufficient robustness and at the same time meets the desired performance specifications regardless of presence of disturbance are the key issues to be addresses.

1.3 Aim and Objectives

The aim of this research is to develop a position controller that capable to move the radio to the desired position with acceptable accuracy and keep accurately pointed even in the presence of disturbance. The following objectives are set in order to achieve the specified aim:

i. To model radio telescope system with wind disturbance
ii. To propose and implement PID controller using slope-variation approach
iii. To analyse the accuracy of the proposed controller technique and its performance.

1.4 Thesis Scope

The scope of this research includes the following:

i. This research focuses on the position control of azimuth axis only because both azimuth and elevation axis work independently, so as its control systems.
ii. Disturbance – generally there are several elements that affect the performance of system which origin from internal and external factor. Nevertheless, wind gust disturbance is one of the important factor that could substantially affect the performance of the radio telescope system.
iii. The wind disturbance is design based on wind speed in Malaysia with minimum speed 10 knot and maximum speed 81.06 knot.
iv. The proposed PID controller tuning technique is specifically designed for position control of a single axis application.

1.5 Contribution

This research focus on the control part as it is the back bone in achieving the desired output. The main contribution of this research is introducing an optimal tuning approach for PID controller where it could outperform the typical ZN and ZN+ method. This proposed approach also provides better solution when compared with gradient descent method since gradient descent employ iterative method that requires more time. The slope variation approach is able to reduce the tedious work in tuning process while maintaining its satisfying performance.

1.6 Thesis Organisation

The remaining parts of the thesis are organised as follow:

Chapter 2: Starts with review and introduction on the radio astronomy current progress and its frequency band. Following that, is the literature search on the radio telescope model and control technique available. It is then summarised the previous research done on controlling the position of the radio telescope system.

Chapter 3: Describes the methodology of this research. The radio telescope system is modelled based on the mathematical equations and it is presented in this chapter. These equations are then translated into model block in SIMULINK. Afterwards, PID controllers are designed where the proposed technique is demonstrated too. The basic knowledge and operation of PID controller and proposed technique is explained.

Chapter 4: Discuss the analysis of results and discussions of the PID and the proposed slope-variation technique. The proposed technique is tested by introducing wind gust disturbance which also presented in this chapter.

Chapter 5: Presents the conclusion drawn from this research and its future direction and recommended work

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LIST OF PUBLICATIONS

Journal Articles

N. Mohamad Zaber, A.J. Ishak, A. Che Soh, M.K. Hassan. “Performance analysis of radio telescope position control using PID and fuzzy logic controller” Advanced Science Letters, vol. 22, no. 10 (2016), pp. 2686 – 2689

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