Journal of Engineering and Applied Sciences 14 (16): 5657-5664, 2019
ISSN: 1816-949X
© Medwell Journals, 2019

Antenna Azimuth Position Control System using Model Reference Adaptive Control Method Gradient Approach and Stability Approach

Aveen Uthman
Department of Communications Engineering, Sulaimani Polytechnics University (SPU), Kurdistan Region, Iraq
aveen.hassan@spu.edu.iq

Abstract: Differential and power amplifiers are the main components of the antenna azimuth position control system. They played an important role in operating the overall system. This study utilized two approaches namely, the gradient and Lyapunov approaches for tuning the differential amplifier gains adaptively by using the Model Reference Adaptive Controller (MRAC). The design process of such controller is demonstrated. Preferred gain value is selected as a reference model. Although, gradient approach shows staggering system response in the overall system's stability, this leads to the introduction of Lyapunov approach to overcome the instability. The two approaches are compared for performance analysis and it was noted that gradual increment in the adaptive gain resulted to improvement in stability for both approaches at some range after which the system response became instable for gradient approach. The rate of improvement is higher in Lyapunov approach with adaptive gain of 450 as against that of the gradient approach with adaption gain of 22. Moreover, Lyapunov settling time was found to be less than that of the MRAC. The gradient approach proved to be slow in system response when the system's input was increased. Moreover, for an adaptive gain of 22 and 450 the best system performance was achieved for gradient and Lyapunov approaches, respectively while the input unit step was maintained as 1. Finally, an improvement on the system response in term of stability and fastness was found in the Lyapunov approach as against the gradient approach.

Key words: Antenna, azimuth position, gradient, Lyapunov, MRAC controller, staggering

INTRODUCTION

The control of antenna azimuth position is a control challenging problem that attracts researchers to propose various techniques for such system. The azimuth positioning of an antenna involves directly in its performances as well as its system response characteristic (Nise, 2000). Hoi *et al*. (2015) carried out an investigation on satellite tracking by comparing the fuzzy Proportional Integral Derivative (PID) techniques with the conventional PID controller to obtain the best in satellite tracking maneuvering. Both techniques were unable provide good tracking and they as well resulted to chattering phenomena which lead to not properly tracking the reference signal for precise positioning. Xuan *et al*. conducted a research work on discrete control system by utilizing PID controller for better control on satellite antenna angle deviation. The shortcoming of this research suffers for the lack of proper tuning of the PID gains. Soltani *et al*. (2011) investigated an overseas satellite telecommunication, a controller was designed and applied to an on-board motorized antenna, another controller was designed to detect fault in the satellite control. Though the controller was not robust enough to enable handle the detected fault in the controlled signal. The research work of Ahmed *et al*. (2014), Astrom and Hagglund (1995) used PID and Linear Quadratic Gaussian (LQG) for the control of antenna azimuth position, similar shortcomings of degraded performance due to system nonlinearities and delay in reaching setpoint was experienced by Ahmed *et al*. (2014), Astrom and Hagglund (1995). A good settling time and less overshoot were achieved by Okumus *et al*. (2012) where Fuzzy Logic Ccontroller (FLC) and a Self-Tuning Fuzzy Logic Controller (STFLC) was utilized in the design, though chattering phenomena were reported as the setback. The pole placement technique for state-feedback controller was investigated by Aveen and Shahdan, Aloo *et al*. (2016) were better transient response was achieved but with overshoot and chattering. The aforementioned makes the antenna azimuth positioning a challenging control problem; hence, there is need for a high-performance controller to handle the shortcomings.

The model reference adaptive controller with both approach; gradient and stability approach are proposed to tune the unknown amplifier gain. This will handle the

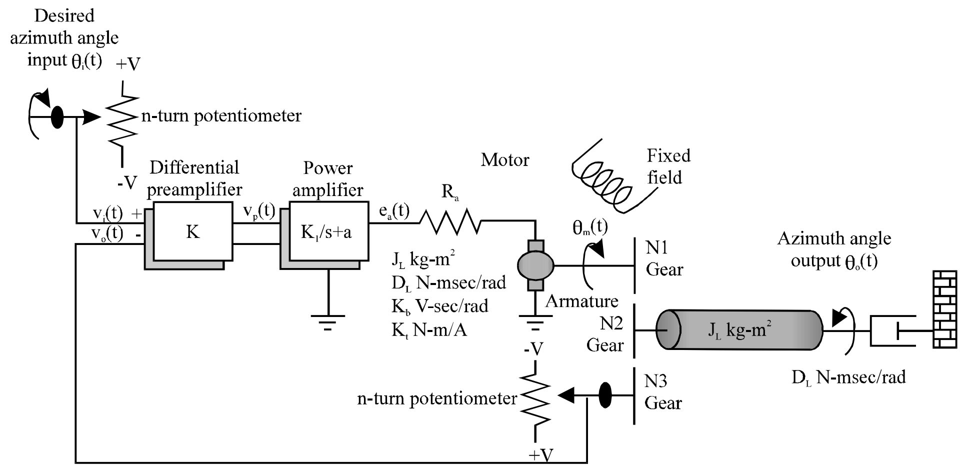

Fig. 1: Schematic diagram of antenna-azimuth position controlling system

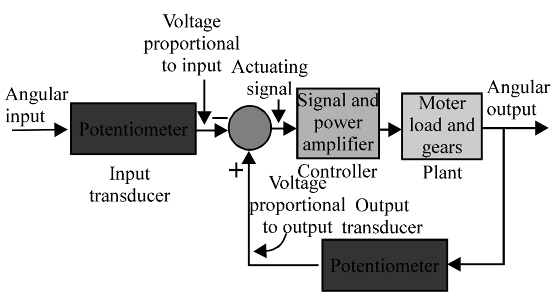

Fig. 2: Block diagram of antenna-azimuth position controlling system

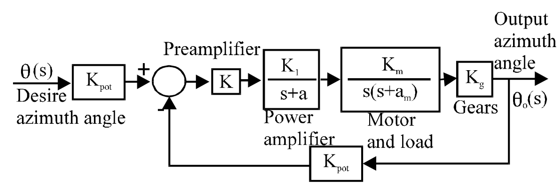

Fig. 3: Block diagram in detail of antenna azimuth control system

issues related to the antenna azimuth positioning and also to prevent the lapses experienced in literature. The two approaches are to be compared to enable justify the best approach in terms of performance with precise azimuth positioning, less overshoot, less settling time, more stable and absent of chattering.

Mathematical modeling of the system: For the control of the telescope antenna, two potentiometers were used with one at the input and the other at the output as transducer. Five subsystems made up the overall system in which each subsystem is of relatively transfer function. Figure 1 and 2 shows a detailed schematic diagram and block diagram of the antenna azimuth position, respectively.

The potentiometer processes the turning of the input rotation angle to voltage and then returned the input via feedback. The effect of both gain and signal increases with the alteration of the input and output voltage. Hence, error becomes zero; this implies that the motor is at rest.

Figure 3 shows more comprehensive block diagram which indicates the controlling of the positioning of the antenna. In this study, the antenna is considered as a load while both gears and the loads are connected to the motor. The motor transfer function can be written as follows:

$$\frac{\theta_m(s)}{E_a(s)} = \frac{\dfrac{K_t}{J_m R_a}}{s\left(s+\dfrac{D_m R_a + K_b K_t}{J_m R_a}\right)} \quad (1)$$

where, R_a, K_t and K_b are the motor's resistance, the back EMF and torque constant of the motor, respectively. Damper and inertial are related to the motor via. gear sets which makes it easier to adjust their operative value in the developed mathematical model:

$$Kg = \frac{N1}{N2} = 0.1$$

Where, N1 and N2 represent the gear teeth:

$$J_m = J_a + J_L\left(Kg^2\right) = 0.03$$

Table 1: Parameters of antenna block diagram

Parameters	Configurations
K	----
K_{pot}	0.318
Ra	100
K_1	100
K_g	0.1

where, J_L is the load inertia at θ_o. The equivalent viscous damping D_m, at the armature is:

$$D_m = D_a + D_L\left(Kg^2\right) = 0.02$$

where, D_L is the load viscous damping at θ_o. From the problem statement $K_1 = 0.5\ Nm^{-1}A$, $K_b = 0.5\ Vs^{-1}rad$ and the armature resistance $R_a = 8\ \Omega$. So, motor and load the transfer function would be. Substituting in Eq. 1 it gives (Eq. 2):

$$\frac{\theta_m(s)}{E_a(s)} = \frac{2.083}{s(s+1.71)} \tag{2}$$

The product of the gear ratio and Eq. 2 must be obtain for the motor transfer function; this is to give the ratio of load displacement to armature voltage Eq. 3:

$$\frac{\theta_o(s)}{E_a(s)} = 0.1\frac{\theta_m(s)}{E_a(s)} = \frac{0.2083}{s(s+1.71)} \tag{3}$$

The preamplifier parameters for power and gears of the above block diagram are given in Table 1. In Table 1 gain value is unknown which represents the preamplifier gain. The related model of each subsystem of antenna azimuth control system is shown for each transfer function in Fig.4. Consecutively, the final closed-loop system model is as obtained in Eq. 4:

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{6.63K}{s^3+101.71s^2+171s+6.63K} \tag{4}$$

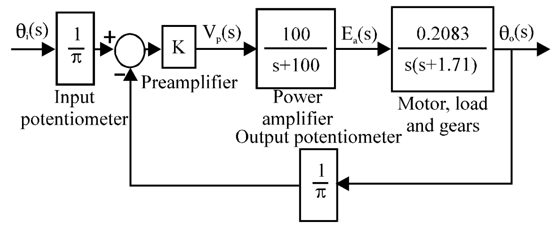

Fig. 4: The related model of every subsystem of antenna azimuth control system

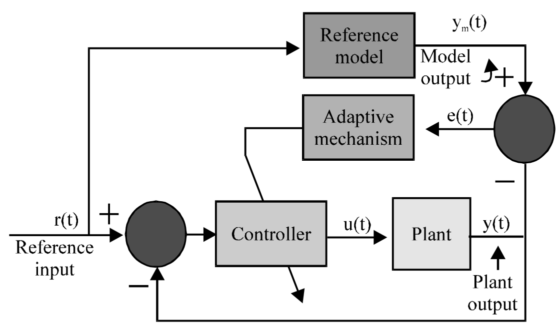

Fig. 5: General structure of MRAC system. Figure 5 is a closed loop MRAC with the following parameters: r(t) Reference input signal; u(t) Control signal; y(t) Plant output; $y_m(t)$ Reference model output; e(t) Difference between plant and reference model output $y_m(t)$

MATERIALS AND METHODS

Model reference adaptive control: An adaptive controller was considered as a powerful controller used for the control of the plant parameter to achieve good system dynamic behavior. An achievement in using adaptive means of control was reported in term of system performance and robustness (Uthman and Sudin, 2018; Ogata, 2010). Hence, MRAC controller was used for its ability of self-tuning the system's parameters to optimum required parameters for an appropriate dynamic behavior (Oltean *et al*., 2016). The basically, MRAC controller structure involves in the design are as shown in Fig. 5:

- Plant to be controlled
- Reference model to generate desired closed loop output response
- Controller that is time-varying and whose coefficients are adjusted by adaptive mechanism
- Adaptive mechanism that uses 'error' (difference between the plant and the desired model output) to produce controller coefficient

Regardless of the actual system's parameters, MRAC takes an adjustment of the controller coefficients for the resulting closed-loop control system to adopt the reference model. By so doing the actual parameter values of the controlled system do not really matter (Astrom and Wittenmark, 1995).

MRAC has two main approaches design process, namely the gradient and Lapunove approach. Pankaj *et al*. (2011) compared the (Massachusetts Institute of Technology) MIT rule and Lyapunov rule for developing an adaptation mechanism on the basis of different time response specifications for the first order system (Liu *et al*., 2004). The results shows that the constant (adaption gain) has an important role in the nature of adaptation, hence it should be chosen correctly. In this study, both the two approaches were considered as shown in section 3.1 and 3.2.

Adaptive gain design with gradient approach MRAC: The gradient approach known as the MIT rule was developed at the MIT, USA. Though this approach is relatively simple in design and easy to use but it has some weaknesses such as stability problem. For this reason, other MRAC approach was introduced to overcome these issues (Hassan and Sudin, 2014; Pankaj *et al*., 2011; Uthman and Sudin, 2013).

MRAC design begins with the tracking error (e) which is defined to be equal to y-y_m where y and y_m as previously defined. It is of great important in MRAC design for the plan output to follow the reference model output throughout the simulation period. Therefore, the tracking error would be minimized by designing a controller with adjustable parameters such that a certain cost function would be minimized. In this study, the change of the gain value of differential amplifier (K) is to be accommodated by the design of such adaptive approach. Routh-Herwitz criterion was adopted for the utilization in obtaining the preamplifier gain value, to enable the system to reach stability fast. According to the set criteria, the system will be considered as stable in term of response if and only if the value of K taken is in the range of 0-262.3 (Chishti *et al*., 2014). Temelkovski and Achkoski (2014) stated that the best value of K for better response is within the value 3.16 (Temelkovski and Achkoski, 2014). Based on this, the reference model is to be taken as in Eq. 5, assuming $\theta_i(s)$ = r Eq. 5:

$$y_m = \frac{209.508}{\left(s^3+101.71s^2+171s+209.508\right)r} \tag{5}$$

The control objective is to adjust the controller parameter K, so that, e(t) is minimized. To achieve this, a cost function $J(\theta)$ is chosen and minimized. The chosen cost function is of the form:

$$J(\theta) = \frac{1}{2}e^2$$

$$\frac{\partial J}{\partial e} = e$$

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial e}\frac{\partial e}{\partial \theta}$$

Let θ = K. By redefining, the desired azimuth angle is r and output azimuth angle is y. Now, the plant model will be as shown in Eq. 6:

$$y = \frac{6.63K}{s^3+101.71s^2+171s+6.63K}r \tag{6}$$

Therefore, using the expression of error, it yields:

$$e = y\text{-}y_m \tag{7}$$

After substituting Eq. 5 and 6 in Eq. 7, it gives:

$$e = \frac{6.63\theta}{s^3+101.71s^2+171s+6.63\theta}r\text{-}\frac{209.508}{s^3+101.73s^2+171s+209.508}r$$

Hence, the derivative of the tracking error resulted to:

$$\frac{de}{d\theta} = \frac{6.63r}{s^3+101.71s^2+171s+6.63\theta}\text{-}\frac{6.63^2\theta}{\left(s^3+101.71s^2+171s+6.63\theta\right)^2}r$$

$$\frac{de}{d\theta} = \frac{6.63r}{s^3+101.71s^2+171s+6.63\theta}\text{-}y\frac{6.63\theta}{s^3+101.71s^2+171s+6.63\theta}r$$

For perfect model following, y_m most be equal to y as:

$$\frac{de}{d\theta} = \frac{6.63}{209.508}y_m\text{-}y\frac{6.63}{s^3+101.71s^2+171s+209.508}$$

$$\frac{de}{d\theta} = \frac{6.63}{209.508}y_m\text{-}y\frac{6.63}{209.508r}y_m$$

$$de/d\theta = -\gamma e\begin{pmatrix}6.63/209.508y_m \\ 6.63/\left(209.508r\right)y_{m\,y}\end{pmatrix}$$

$$= -\gamma e\frac{6.63}{209.508}\left(y_m\text{-}\frac{y_m}{r}y\right)$$

$$y_m\text{-}209.508/\left(s^{(3)}+101.71s^{(2)}+171s+209.508\right)y)$$

Lets:

$$\gamma' = \gamma\frac{6.63}{209.508}$$

Then:

$$\theta = -\frac{\gamma' e}{s}\left[y_m\text{-}\frac{209.508}{s^3+101.71s^2+171s+209.508}y\right]$$

As a result:

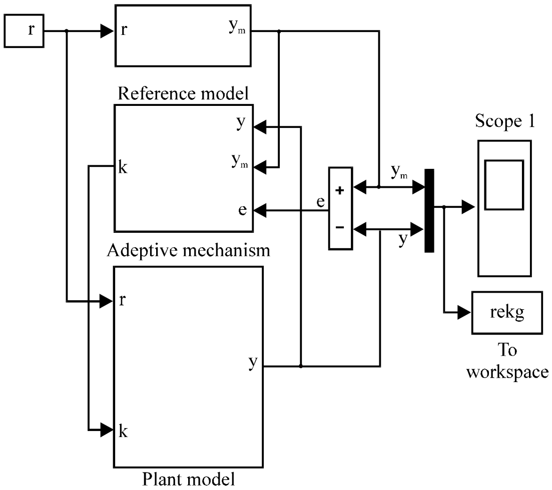

Fig. 6: Gradient approach adaptive gain controller simulation diagram

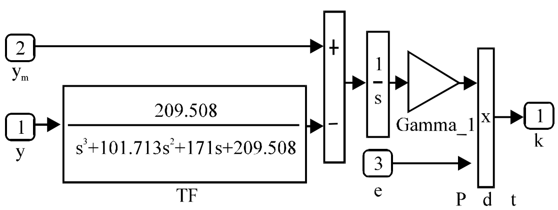

Fig. 7: Simulation diagram of adaptive mechanism

$$K = -\frac{\gamma' e}{s}\left[y_m - \frac{209.508}{s^3+101.71s^2+171s+209.508}y\right]$$

Figure 6 shows the simulation block diagram of gradient approach of adaptive control used for tuning of controller gain while the adaptive mechanism is shown in Fig. 7.

Adaptive controller gain design with lLapunov approach: The globally asymptotic stability can be guaranteed through the Lyapunov second approach. The term Lyapunov approach will be used throughout this study. It requires an appropriate Lyapunov function in the design of MRAC controller such that the output y of the closed loop system is to follow the output of the reference modelthis is to minimize the error ($y-y_m$). This srudy presents a direct adaptive controller design which adapts and accommodates changes in the parameter K. As it is shown earlier in section 3.1, the reference model is:

$$y_m = \frac{209.508}{s^3+101.71s^2+171s+6.63K}r$$

And the plant model is:

$$y = \frac{6.63K}{s^3+101.71s^2+171s+6.63K}r$$

In designing an MRAC using Lyapunov method, the following steps should be followed.

Step 1: Derive a differential equation for error. From Eq. 5 and 6 after replacing the differential equation yields:

$$\dddot{y} = -\left(101.71\ddot{y}+171\dot{y}+\left(\frac{y}{r}-1\right)6.63Kr\right) \tag{8}$$

$$\dddot{y}_m = -\left(101.71\ddot{y}_m+171\dot{y}_m+\left(\frac{y_m}{r}-1\right)209.508r\right) \tag{9}$$

$$\dddot{e} = \dddot{y}-\dddot{y}_m \tag{10}$$

Substituting Eq. 8 and 9 in 10 yields Eq. 11:

$$\dddot{e} = -\left\{\begin{matrix}(101.7)\left(\ddot{y}-\ddot{y}_m\right)+(171)\left(\dot{y}-\dot{y}_m\right)+\\(6.63K)(y-r)-(209.508)(y_m-r)\end{matrix}\right\} \tag{11}$$

Equation 11 can be express as Eq. 12:

$$\dddot{e} = -\left\{\begin{matrix}101.73\ddot{e}+171\dot{e}+6.63K(y-r)-\\209.508(y_m-r)\end{matrix}\right\} \tag{12}$$

Step 2: Find a suitable Lyapunov function, usually in a quadratic form. The Lyapunov function is:

$$V\left(\ddot{e},\dot{e},e,X\right) = \left[\ddot{e}\dot{e}eX\right]\begin{bmatrix}\lambda_i & 0 & 0 & 0\\0 & \lambda_{ii} & 0 & 0\\0 & 0 & \lambda_{iii} & 0\\0 & 0 & 0 & \lambda_{iv}\end{bmatrix}\begin{bmatrix}\ddot{e}\\\dot{e}\\e\\X\end{bmatrix} \tag{13}$$

$$V = \lambda_i\ddot{e}^2+\lambda_{ii}\dot{e}^2+\lambda_{iii}e^2+\lambda_{iv}X^2$$

where, λ_i, λ_{ii}, λ_{iii}, $\lambda_{iv}>0$, so that, is positive definite. The derivative of becomes:

$$\dot{V} = 2\lambda_i\ddot{e}\dddot{e}+2\lambda_{ii}\dot{e}\ddot{e}+\lambda_{iii}\dot{e}e+\lambda_{iv}X\dot{X}$$

$$\dot{V} = -2\lambda_i\ddot{e}\left(101.73\ddot{e}+171\dot{e}+6.63K(y-r)-209.508(y_m-1)\right)+$$

$$w2\lambda_{ii}\dot{e}\ddot{e}+\lambda_{iii}\dot{e}e+\lambda_{iv}X\dot{X}$$

where, $\dot{V}$ for stability must be negative i.e., $\dot{V} \prec 0$.

Step 3: Derive an adaptation mechanism based on $V\left(\ddot{e}, \dot{e}, e, X\right)$ such that e goes to zero:

$$\dot{X} = -6.63\ddot{e}\frac{\lambda_i}{\lambda_{iii}}(y-r)\lambda_i = -\frac{\lambda_i}{\lambda_{iii}}$$

Since, K = X:

$$\therefore K = -6.63\ddot{e}\frac{\lambda_i}{\lambda_{iv}}(y-r), \text{ Let } \lambda = -\frac{\lambda_i}{\lambda_{iv}}$$

$$\therefore K = -6.63\ddot{e}\lambda(y-r)$$

Figure 8 shows the simulation block diagram of Lyapunov approach adaptive control used for tuning of controller gain K. Figure 9 shows the adaptive mechanism block diagram. Table 2 shows the comparison of both the gradient and Lyapunov approach gain K in term of equation form.

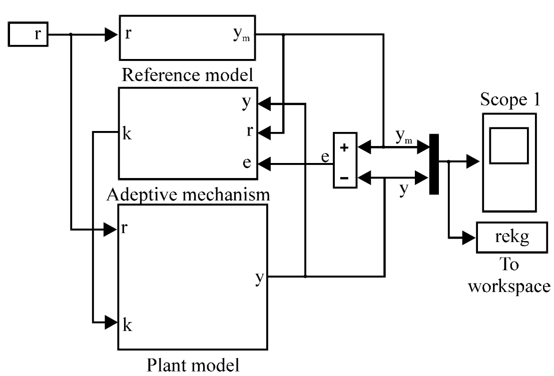

Fig. 8: Lyapunov approach adaptive gain controller simulation diagram

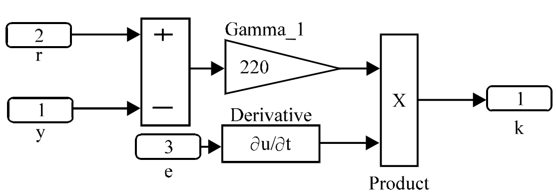

Fig. 9: Simulation diagram of adaptive mechanism

Table 2: The gradient and Lyapunov approach gain K

Gradient approach design	Lyapunov design approach
$K = -\frac{y_m\gamma'e}{s} + \left[y_m - \frac{209.508\gamma'ey}{s(s)^3+101.71s^2+171s+209.508}y\right]$	$K = -y\ddot{e}6.6\lambda+6.6\lambda r$

RESULTS AND DISCUSSION

Both MRAC controller design approaches have been designed for antenna azimuth position control with the aim to tune the gain adaptively. The simulation is done using MATLAB platform and result will be presented via. simulation. Figure 10 and 11 presents the plant time response (y) of both the two approaches (Gradient and Lyapunov) when several adaption gain values are applied. As shown in Fig. 10 the range of accepted adaption gain values with better plant responses was found at $18<\gamma'<22$ for gradient approach. Beyond the stated range the system goes out of stability at high values of adaption gain and also the system time response is very slow at low adaption gain values as examined in Fig. 10. On the other hand, (Fig. 11) shows best plant time response when the adaption gain is chosen around 450 for Lyapunov approach. At small value of adaption gain the system response is slow and has small amount of overshot at peak time region. Moreover, the response has high steady

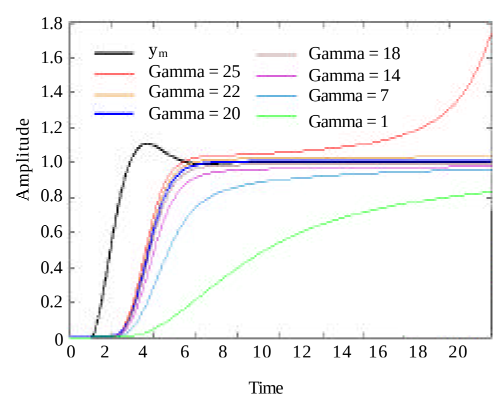

Fig. 10: Output azimuth angle response by applying different gamma values-gradient approach

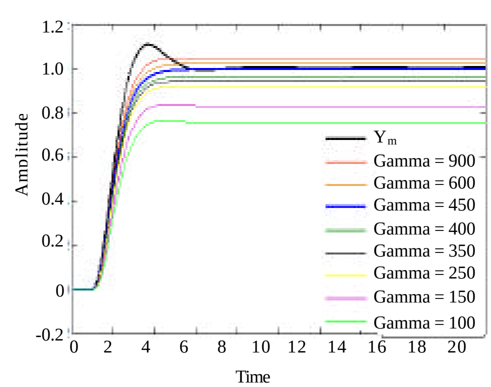

Fig. 11: Output azimuth angle response by applying different gamma values-Lyapunov approach

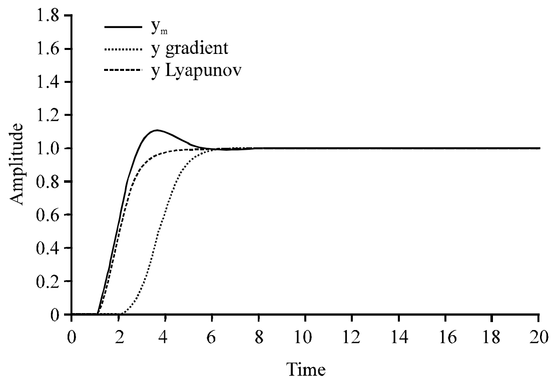

Fig. 12: Gradient approach response versus Lyapunov approach response

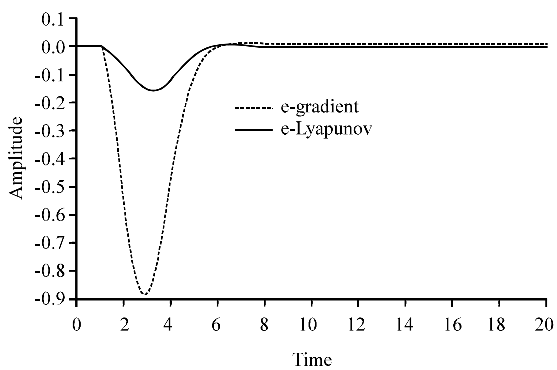

Fig. 13: Difference between y and ym for both adaptive controller approaches

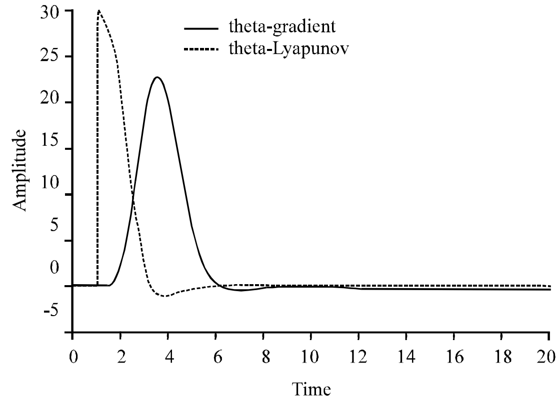

Fig. 14: Variation of control parameter (θè) of both controller approaches

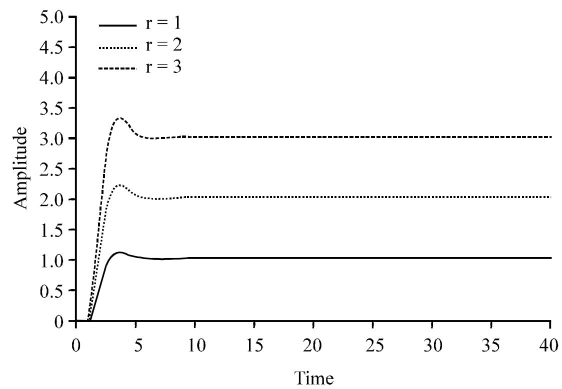

Fig. 15: System response (y) with different input value in Lyapunov approach

state error when high value of adaption gain is applied. Worth mentioning, both adaption gains γ' and λ are denoted by gamma in the simulation diagram.

Moreover, Fig.12 shows the plant response (y) of both approaches (Gradient and Lyaponov) with respect to the desired model reference (y_m). According to Fig. 12, the plant model responses of the two approaches are both trying to follow the reference model. In fact, there are fewer differences in responses with the Lyaponov approach from 2-5.8 sec while the gradient approach is slow and spends more transient time to reach the steady state response with great differences in response from 2-6 sec.

In addition, the error e and the variation of controller parameter (θ) for both approaches has been shown in Fig. 13 and 14, respectively. It can be observed that the error in gradient approach converges longer than the Lyapunove approach. In the gradient approach the error converges to≈-0.9 which is significantly large, while in Lyapunov approach it converges to≈-0.15. The error in both approaches reaches zero at the same time (6 sec).

Figure 14 shows how the controller parameter (θ) converges to 22 with respect to time for gradient approach when the adaptive gain is 22 while Lyapunov approach indicated converges to 30 with respect to time when the adaptive gain is 450.

Furthermore, result analysis could be gathered by increasing the input of the system (r) which is angular position input θ_i on the real system. Figure 15 and 16 shows the system response achieved when different values of r are applied for both the adaptive controller approaches. According to the Lyapunov approach (Fig. 15), the system efficiency and stability are not significantly by changes in the system input. While in gradient approach the stability of the system is significantly affected with changes in the system input as shown in Fig. 16.

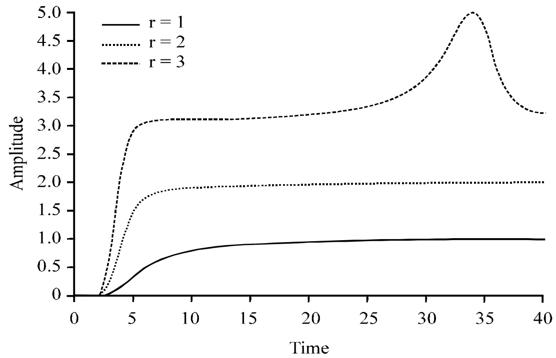

Fig. 16: System response (y) with different input value in gradient approach

CONCLUSION

Two approaches of model reference adaptive controller have been designed for antenna azimuth position control system. Comparison analysis has been done with the system response and performance of the two approaches. The gradient approach is simpler in term of design and modeling while the complicacy was reduced in configuration of MRAC with Lyapunov rule. Although, of the simplicity of gradient approach, it has some sudden stability threatens for an increases in the adaption gain. Lyapunov approach was introduced to overcome the said stability issues. The adaption gain is an important factor that affects the system response directly, thus, it should be chosen reasonably. It was noted gradual increase in the adaptive gain, resulted to improvement in stability for both approaches until it reaches some range after which the system response became instability for gradient approach. The rate of improvement is higher in Lyapunov approach with adaptive gain of 450 as against that of the gradient approach with adaption gain of 22. Hence, Lyapunov rule proved to be more stability than the gradient approach. Moreover, Lyaapunov settling time is also less for the MRAC which improves the speed of the system. The gradient approach proves to be slow in system response when increasing the system's input. It can be concluded that system performance is best for adaptive gain of 22 and 450 for gradient and Lyapunov approaches, respectively while the input unit step was maintained as 1.

REFERENCES

Ahmed, M., S.B.B.M. Noor, M.K.B. Hassan, A.B.C. Soh, 2014. A review of strategies for parabolic antenna control. Aust. J. Basic Appl. Sci., 8: 135-148.

Aloo, L.A., P.K. Kihato and S.I. Kamau, 2016. DC servomotor-based antenna positioning control system design using hybrid PID-LQR controller. Eur. Intl. J. Sci. Technol., 5: 17-31.

Astrom, K.J. and B. Wittenmark, 1995. Adaptive Control. 2nd Edn., Addison Wesley, Boston, Massachusetts, ISBN:9780201558661, Pages: 574.

Astrom, K.J. and T. Hagglund, 1995. PID Controllers: Theory, Design and Tuning. 2nd Edn., International Society of Automation, ?Research Triangle Park?, North Carolina, ISBN-13: 978-1556175169, Pages: 343.

Chishti, A.R., S.F.R.R. Bukhari, H.S. Khaliq, M.H. Khan and S.Z.H. Bukhari, 2014. Radio telescope antenna azimuth position control system design and analysis in MATLAB/Simulink using PID and LQR Controller. Master Thesis, Islamia University, Bahawalpur, Punjab, Pakistan.

Hassan, A.U. and S. Sudin, 2014. Road vehicle following control strategy using model reference adaptive control method stability approach. J. Teknologi, 72: 111-117.

Hoi, T.V., N.X. Truong and B.G. Duong, 2015. Satellite tracking control system using fuzzy PID controller. VNU. J. Sci. Math. Phys., 31: 36-46.

Liu, X.J., F.L. Rosano and C.W. Chan, 2004. Model-reference adaptive control based on neurofuzzy networks. IEEE. Trans. Syst. Man Cybern. Part C Appl. Rev., 34: 302-309.

Nise, N.S., 2000. Control Systems Engineering. John Wiley and Sons, USA.

Ogata, K., 2010. Modern Control Engineering. 5th Edn., Prentice-Hall, New Jersey, USA.,.

Okumus, H.I., E. Sahin and O. Akyazi, 2012. Antenna azimuth position control with classical PID and fuzzy logic controllers. Proceedings of the International Symposium on Innovations in Intelligent Systems and Applications, July 2-4, 2012, IEEE, Trabzon, Turkey, pp: 1-5.

Oltean, S.E., M. Dulau and A.V. Duka, 2016. Model reference adaptive control design for slow processes: A case study on level process control. Procedia Technol., 22: 629-636.

Pankaj, S., J.S. Kumar and R.K. Nema, 2011. Comparative analysis of MIT rule and Lyapunov rule in model reference adaptive control scheme. Innovative Syst. Des. Eng., 2: 154-162.

Soltani, M.N., R. Izadi-Zamanabadi and R. Wisniewski, 2011. Reliable control of ship-mounted satellite tracking antenna. IEEE. Trans. Contr. Syst. Technol., 19: 221-228.

Temelkovski, B. and J. Achkoski, 2014. Modeling and simulation of antenna azimuth position control system. Intl. J. Multidiscip. Curr. Res., 2: 254-257.

Uthman, A. and S. Sudin, 2013. Controller gain tuning for road vehicle convoy system using model reference adaptive control method. Intl. J. Res. Eng. Sci., 1: 1-10.

Uthman, A. and S. Sudin, 2018. Antenna azimuth position control system using PID controller and state-feedback controller approach. Intl. J. Electr. Comput. Eng., 8: 1539-1550.