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Model-Free Based on La-Lead Compensator for Antenna Azimuth Position

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Abstract:

This research intended to control the positioning of antenna azimuth system with a model-free controller. The model-free controller presented here, has proven to be able to reach comparable performances than advanced techniques controllers. The model-free controller design has a simple structure, its implementation and tuning rule are simple, and does not need any special knowledge about control theories and modelling of the system. It is more efficient than some advanced controllers such as LQR, FLC, QFT, because it can reach similar performances than these controllers, but with less requirements in term of time and effort needed to design the controllers and to tune it, when requested.

Keywords **—Antenna azimuth, Model-free controller, Proportional integral derivative controllers (PID), Fuzzy Logic Controllers (FLC), Linear Quadratic Regulator (LQR), Quantitative feedback theory (QFT).**

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I. INTRODUCTION

An antenna is a necessary component of any wireless system [1]. Wireless communication systems have been more and more important in day to day live with the development of digital cellular networks, wireless networking for internet access, wireless sensor networks, point-to-point wireless connectivity, mobile broadcasting systems, navigation satellite systems. The antenna positioning system is required to reduce the pointing error which will enable to receive highest signal strength. Moreover, the increased size of antennas, creates multiple pointing and control challenges [2]. Several techniques were proposed to achieve an optimum control of the azimuth position but such positioning remains a control challenging problem [3]. PID controllers were proposed [4], [3], Fuzzy logic controllers were used and showed better performances than PID [5], hybrid PID-LQR controller [6], and Quantitative feedback theory [7] also showed good performances.

Most of the cited methods used a mathematical model of the system to derive the right control strategy to apply on it. In this paper, we explore a different approach; we try to control the positioning of an antenna azimuth without knowing the model of the system. Since the antenna azimuth is well-known and many studies have successfully managed to control it for decades, it is not efficient to still rely on mathematical modelling and advanced control techniques to end with performances that can be easilyobtained with less efforts. Model-free controllers could be very useful for antenna azimuth positioning as they do not depend on the model of the system. Furthermore, the antenna system can be subject to environment changes (wind, dust, etc.) and non-linearities, which are very hard to model in order to design the proper controller.

The purpose of this study is to design a Model-free controller that is efficient in term of performances and operability (easy to realize and operate). The design time requirement should be minimum and the tuning rule should be simple.

II. MODEL-FREE CONTROLLER

There are already some model-free controllers present in the literature, for which we can extract two main:

- Model-free controller based on the Ultra local model [8], [9];
- Model-free controller based on Pseudo-partial derivative [10].

The above model-free controllers have been implemented with success, but there is no tuning rule proposed in case the need to refine the controller parameters arises. In addition, there are not easy to implement, and may request a lot of expertise to determine the value of the controller parameters. Thus, they do not meet our fixed requirement to be easy to implemented and easy to tune.

The proposed model-free controller has a simple structure, it can be implemented easily by software or hardware. It does not need the mathematical model of the system to be controlled.

The below figure (fig.1) represents the principle of the proposed model-free controller, which consists of two parts:

- The in-loop part, composes of a Derivative controller, which role is to eliminate the pure integral of the plant, and reduce the disturbances;
- The out-loop, compose of a lag-lead compensator, which roles is to transform the input signal to a more suitable signal such that the in-loop part can use it to achieve the control objectives.

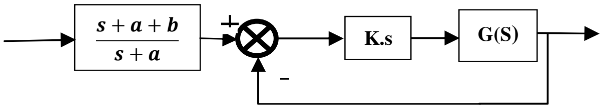

Figure 1: Block diagram of the Model-free controller.

A. *Model free controller Parameters and objective*

From fig.1, we can see that the controller has three parameters, "***K***", the derivative gain, "***a***" and "***b***".

These last two are the main controller parameters, used to refine the plant performances. In order to reduce the complexity, a mathematical relation between "a" and "b" was extracted. In this way, only one parameter is needed (we choose arbitrary the parameter "***a***"), the other parameter, "***b***" in this case, is drive from a mathematical given relation.

B. *Stability analysis*

The system is stable if the plant, represented by ***G(S)*** is stable and the out-loop compensator is stable as well.

$$System\ stable\ if\ \begin{cases} if\ G(S) stable \\ a > 0 \end{cases},$$

C. *Error analysis*

The antenna block diagram is represented in the fig. 2 below [11].

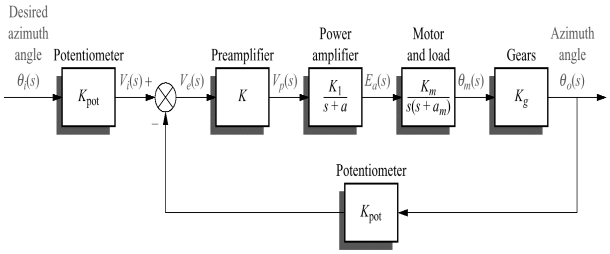

Figure 2: Block diagram of antenna azimuth position before introduce the controller.

Let assume that the antenna is represented by the transfer function:

$$\frac{\theta_0}{\theta_i} = G(s) = \frac{K_p}{s^3+l_1 s^2+l_2 s} (1)$$

Then, the block diagram of the all system can be represented by the fig.3.

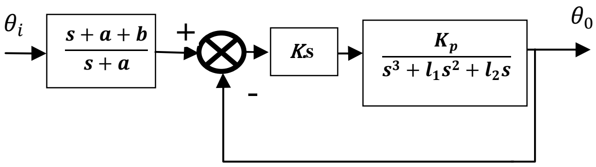

Figure 3: Block diagram of the system with the model-free controller.

From fig.3, we derive the complete transfer function as:

$$\frac{\theta_0}{\theta_i} = \frac{KK_p}{s^2+l_1 s+l_2+KK_p} \cdot \frac{s+a+b}{s+a} \quad (2)$$

Applying the final value theorem, we obtain:

$$V_f = \lim_{s\to 0} \frac{KK_p}{s^2+l_1 s+l_2+KK_p} \cdot \frac{s+a+b}{s+a} \quad (3)$$

$$\boldsymbol{V_f} = \frac{KK_p}{l_2+KK_p} \cdot \frac{a+b}{a} \quad (4)$$

with,

$$\frac{KK_p}{l_2+KK_p} = \textit{antenna closed\_loop final value } (V_{cl})$$

$$\frac{a+b}{a} = \textit{out\_loop compensator final value}$$

$$\boldsymbol{V_f} = \boldsymbol{V_{cl}} \cdot \frac{a+b}{a} \quad (5)$$

The system final value depends on two sub-systems the in-loop closed loop sub-system ($\boldsymbol{V_{cl}}$) and the out-loop sub-system.

Let us compute the error ***E***,

$$E = \theta_i - V_f \quad (6)$$

(5) in (6), $E = \theta_i - V_{cl} \cdot \frac{a+b}{a}$ (7)

From (7), we can derive the value of ***b*** as:

$$b = a\left(\frac{\theta_i - E}{V_{cl}} - 1\right) \quad (8)$$

If we want to drive the error to zero, we set E=0 from (8), then we can compute the value of ***b***:

$$b = a\left(\frac{\theta_i}{V_{cl}} - 1\right) \quad (9)$$

To find ***"b"*** we only need to know the closed loop system final value (V_{cl}), ***"a"*** is the model-free parameter that is used to improve the system performance.

"a" is a positive real number, initially set to ***a=1***, can be increase or decrease. V_{cl} is determine by experiment, only by using the system and the in-loop controller and take the stable final value for the desired input.

III. SIMULATIONS

The simulations were conducted using the transfer functions for the antenna system as described by Okumus [4], Suresh [7], and Linus [6]. The software used for the simulation was Scilab version 5.5.2.

$$\frac{\theta_0}{\theta_i} = \frac{6.63}{s^3+101.71s^2+171s} \quad (10)$$

After applying the in-loop of the model-free controller we have:

$$\frac{\theta_0}{\theta_i} = \frac{6.63K}{s^2+101.71s+171} \quad (11)$$

A. *Model-free controller parameters 1st simulation:*

K=1, a=1, b=25.79 from (9), with $V_{cl} = 0.008$, sample time=1ms.

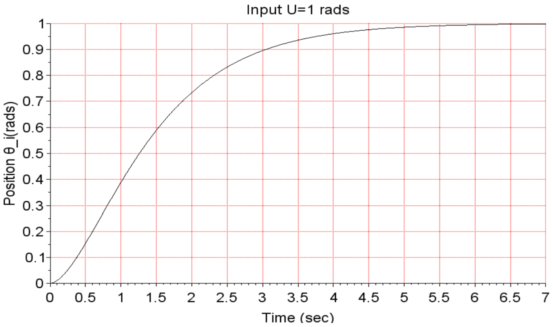

Figure 4: Step response of the system with K=1, a=1, b=25.79.

The step response of the system with model-free controller shows that there is no overshoot, no error and the settling time is Ts=4.14s.

Although, the model-free controller achieved a good "overshoot" and "No error", in the first try with K=1, a=1 (the only parameters to be tuned), its settling time is very low compared to the one obtained by advanced controller (see table 1, below).

Therefore, there is a need for tuning the controller parameters to meet settling time requirements of the advanced controllers.

In the second simulation we tried to improve the system response, by increase the value of "*K*" *and* "*a*".

B - Model-free controller parameters 2nd simulation

K=600, a=10, b=0.43 from (9), with $V_{cl} = 0.959$, sample time=0.1ms.

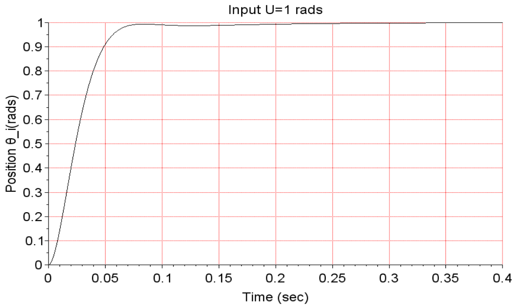

Figure 5: Step response of the system with K=600, a=10, b=0.43.

The system now, has good performances similar to the performances obtained with advanced controller techniques as shows in the comparative table below:

TABLE I:TABLE 1. COMPARATIVE TABLE FOR DIFFERENT CONTROL TECHNIQUES.

Parameter	**Settling time (S)**	**Overshoot (%)**	**Error (rads)**
PID **Proportional, Integral Derivative**	0.8	23.5	0
LQR **Linear Quadratic Regulator**	2.4	<4	1
PID-LQR	1	5	0
FLC **Fuzzy logic Controller**	0.125	0	0
STFLC **Self turning FLC**	0.05	0	0
QFT **Quantitative Feedback Theory**	0.09	2.24	0.0033
MFC **Model-free controller**	0.07	0	0

For the system used, the tracking specifications were defined as follow [7]:
$OS(\%) \leq 12\%, Ts < 0.2\ sec, Error < 1\%$.

From table 1, we can see that the model-free controller designed here has reached the desired specifications, and its performances are similar to those of STFLC and QFT, without the need to know system parameters or model. It is enlighten that the model-free controller required small amount of time for its design and it is easy to tune without the need to know any equation or rules, its performances are very near to the one of advanced techniques for the system used here.

IV. CONCLUSIONS

We have achieved the design of a simple model-free controller easy to use and to implement, however its performances are similar to those of some advanced control technique (LQR, FLC, QFT etc.) for the control of antenna azimuth position. The tuning was reduced to a trivial increase of two parameters "K" and "a". It only requires to know the system closed-loop final value, which can be known by a prior test. Theoretically, this model-free controller can be designed in few minutes, thus it will save a lot of time to the control system engineer. It also does not required a particular knowledge of system model, to be able to tune it, making it suitable for industries. The future work will be directed to simulation in laboratory with real system, the studies of the effects of disturbances and the design of an intelligent model-free controller which may be useful to minimize the effects of disturbances and the non-linearities.

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