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Disturbance Rejection Control Approach for Rotating Antenna

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ABSTRACT: In this work, we propose designing a system that has approximately the same idea as the radar's operation concept. The representative process control challenges are tackled using a new control technique called Active Disturbance Rejection Control (ADRC) to solve tracking control problems. An additional state variable, that is calculated and adjusted in real time, is the disturbance and the unmeasured dynamics related to the antenna. This disturbance and the unmeasured dynamics are handled in the ADRC framework. This controller is applied to drive and rotate the antenna to the appropriate locations in 2D in real-time using two DC motors that operate independently. The ADRC estimates the internal and external disturbances using an extended state observer (ESO). A simulation study is performed on two ADRC controllers and DC motors which give excellent results and drive the antenna successfully to the desired position in two cases: without and with external disturbances.

Keywords: **DC motors, antenna, extended state observer, and active disturbance rejection control.**

الملخص: في هذا العمل، اقترحنا تصميم نظام له نفس فكرة تشغيل الرادار تقريبًا. تتم معالجة تحديات التحكم التمثيلي في العمليات باستخدام تقنية تحكم جديدة تسمى التحكم النشط في رفض الإزعاج (ADRC) لحل مشكلات التحكم في التتبع. هناك متغير إضافي للحالة، يتم حسابه وضبطه في الوقت الفعلي، وهو الاضطراب والديناميكيات غير المقاسة المتعلقة بالهوائي. يتم التعامل مع هذه الاضطرابات والديناميكيات غير المقاسة في إطار عمل ADRC. يتم تطبيق وحدة التحكم هذه لدفع الهوائي وتدويره إلى المواقع المناسبة في ثنائي الأبعاد في الوقت الفعلي باستخدام محركين يعملان بشكل مستقل بالتيار المستمر. يقوم ADRC بتقدير الاضطرابات الداخلية والخارجية باستخدام مراقب الحالة الموسع (ESO). تم إجراء دراسة محاكاة على وحدتي تحكم ADRC ومحركات DC والتي تعطي نتائج ممتازة وتدفع الهوائي بنجاح إلى الموضع المطلوب في حالتين؛ بدون اضطرابات ومع الاضطرابات الخارجية او الطبيعية.

الكلمات المفتاحية: محركات التيار المستمر، الهوائي، مراقب الحالة الممتدة، التحكم النشط في رفض الاضطراب

I. INTRODUCTION

The science of control engineering has proven beneficial to the globe and humanity. To produce beneficial goods for society, control engineering focuses on comprehending and managing aspects of their surroundings, which are sometimes referred to as systems. It is not restricted to regions or academic disciplines. It may be used in variety of majors, including mechanical, electrical, chemical fields, ….etc.

A collection of interconnected parts that make up a system is called a control system. Process is one of the components in the system that is needed to be controlled, and it can be represented by a block diagram.

Additionally, the link between input and output illustrates the process's cause and effect. To get the desired reaction, there are two types of systems: closed loop and open loop control systems with controller and actuator.
In chemical engineering, Active disturbance rejection control (ADRC) was created outside the process control field [(Jingqing, 1998 &1999), (Zhiqiang, Yi, and Jingqing, 2001), (Zhiqiang, 2003 & 2006)]. Motion control, aircraft flight control, web tension adjustment, and other applications have been effectively implemented with its help [(Zhiqiang, Shaohua, and Fangiun, 2001), (Qing and Zhiqiang, 2006), (Yuxin, Baoyan, Chunhong, Zhang, Chen, and Jianwei, 2004), (Yi, Kekang, and Jingqing, 2001), (Bosheng and Zhiqiang, 2005), and (Hou, Zhiqiang, Fangjun, and Brian, 2001]. The applications demonstrate that ADRC produces a very simple controller architecture while achieving grate tracking and disturbance rejection performance for variety of challenging control situations.
Multivariable systems, sometimes referred to as Multi-Input Multi-Output (MIMO) systems, are widely used in industry. Design approaches for multivariable control systems differ significantly from those for Single-Input Single-Output (SISO) control systems due to the interactions or cross-couplings between different inputs and outputs of a system. Disentangling the interactions between different inputoutput pairs and breaking down a multiva riable system into several distinct SISO systems is one design method, since our knowledge of t he physics of MIMO systems typically aids in identifying the dominating input-output pairs.
Granted, this is not the only approach, but in some industries, like radar technology, it is the preferred method.
Antenna or radar systems have a wide range of applications, including weather forecasting, traffic control, navigation, automotive systems, and aviation. In military and defense operations, a radar system can be used to detect, track and distinguish objects in the air, on land, and at the sea. The issue of the antenna azimuth and elevation positions control has become one of the many topics in the electromagnetic, communications, radar systems, and antenna placement (Norman, 2000). Many techniques were proposed and designed to create an ideal control of the azimuth position, but such positioning remains a control challenging problem that the researchers still search and work on. The researches; Mohammed, Samsul, Mohd , and Azura (2014), and Linus, Peter, and Stanley (2016), are basically using PID and Linear Quadratic Gaussian (LQG) for the antenna azimuth position control system; both researchers were faced with similar shortcomings of degraded performance due to system nonlinearities and delay in reaching setpoint.

In this work, we develop a novel remote-control mechanism for the rotating antenna. The antenna location is determined by the applied voltage to the motor. The stability of the Simulink result we obtain determines the required location, and our job is to generate the voltage required to shift the antenna to any given angle. We must first model and study the system to construct the antenna's control mechanism. Additionally, Section II reviews the ADRC's concept. The tracking issues and simulation results resolved in Section III using DC motor and control design of the mathematical model. Section V concludes with some final thoughts.

II. ACTIVE DISTURBANCE REJECTION CONTROL

The SISO and the MIMO problems, as well as nonlinear, time-varying, and most importantly, unpredictable plants, have all been addressed by the active disturbance rejection approach. However, as seen below, the second order motion system is frequently employed for illustrative purposes. The second order nonlinear system model which is applied in this work is considered as:

$$\ddot{y} = f(t, y, \dot{y}, w) = bu \tag{1}$$

where u is the input, b is a generally known parameter as $b \approx b0$, and y is the measured output to be controlled. the combine influence of external disturbances w and internal dynamics is denoted by f. In real life, it is frequently impossible to find a precise mathematical description of f, therefore, ADRC offers a much needed solution to this issue. The main step is that (1) can be reduced to a double integral plant by canceling it with the control signal if f can be calculated in real time. In other words, a linear time-invariant cascade integral plant, which is easily controllable with a PD controller, is roughly equivalent to a nonlinear time-varying unknown plant of (1).
Real time estimates of internal and external disruptions are made at the ADRC using an ESO. Through disturbance rejection, any unclear plant dynamics will be eliminated, reducing the plant tp a straightforward cascade integral plant that is simply to run with a PD controller. Phase lag is introduced into the system when the ESO is used with complete order, and the system (1) can be reformed in the state space form shown below in order to use the ESO.

$$\left.\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= x_3 + b_0 u \\ \dot{x}_3 &= f = \dot{h} \\ y &= x_1 \end{aligned}\right\} \tag{2}$$

where $x_3 = f$ is used to increase the state. When expressed in a matrix form, it turns into

$$\left.\begin{aligned} \dot{x} &= Ax + Bu + Eh \\ y &= Cx \end{aligned}\right\} \tag{3}$$

where;

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ b_0 \\ 0 \end{bmatrix}, E = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, c = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

with h is unknown, the state observer of (3) is

$$\left.\begin{aligned} \dot{z} &= Az + Bu + L(y - \hat{y}) \\ y &= Cz \end{aligned}\right\} \tag{4}$$

Where $y, \dot{y}$ and f are estimated by z_1, z_2, and z_3 , respectively. Since the state vector in (2) is expressed to include f, this observer is called ESO, therefore, its purpose is to offer an estimate of that. It should be noted that if the observer in (4) is properly designed and deployed, its state will track that of the plant in (3).

For instance, the pole placement approach [4] can be used to obtain the parameter vector L. Simply, let $\lambda(s) = |sI - (A - LC)| = (s + \omega_0)^3$, and this yields to $L = [3\omega_0 \quad 3\omega_0^2 \quad \omega_0^3]^T$. There are only two parameters in the ESO: b_0 and ω_0, and the designers are typically familiar with the former which is also obtainable through open loop reaction. The latter is a tuning parameter that represents the observer's bandwidth. Performance and noise sensitivity can be readily traded off by varying ω_0. Now, using $z_3 \approx f$ that was acquired from the ESO, the control law will be as follows:

$$u = (u_0 - f)/b_0 \tag{5}$$

reduces (2) into an double integral plant:

$$\ddot{y} \approx u_0$$

which can be easily controlled using a PD controller of the form:

$$u_0 = k_p (r - z_1) - k_d z_2. \tag{7}$$

Real time estimation of f and cancelation in the control law are the fundamental concept of ADRC. The controller architecture is similar for first order nonlinear systems. Assume that

$$\dot{y} = f + b_0 u \tag{8}$$

the design of the second order ESO is as follows:

$$\dot{z} = \begin{bmatrix} -2\omega_0 & 1 \\ -\omega_0^2 & 0 \end{bmatrix} z + \begin{bmatrix} b_0 & 2\omega_0 \\ 0 & \omega_0^2 \end{bmatrix} \begin{bmatrix} u \\ y \end{bmatrix} \tag{9}$$

where z_1 tracks y and z_2 tracks f, and u is the controller in (5). A proportional control is now used to control and reduce the plant once it has been converted to an integral form as:

$$\dot{y} = u_0 = k_p (r - z_1) \tag{10}$$

III. MATHEMATICAL MODEL OF THE SYSTEM

One of the most important elements in our system is the direct current motor, which is called a DC Motor. A DC motor is designed to utilize electricity to produce mechanical movement. It is used in many control systems that require a certain force to move the mechanical parts to specific positions. In our control system, the antenna is driven by two DC motors to rotate and move until it aligns with the tracked zone. Then the DC motors receive signals from the sensors to stop at the desired positions. However, Figure 1 shows a simple DC motor with a shaft that rotates at different speeds.

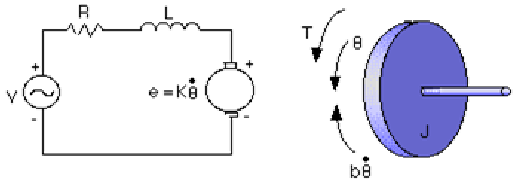

Fig. 1: DC motor.

Then, the mathematical model of the used DC motor can be:

$$\left.\begin{aligned} v(t) &= Ri + L\,\frac{di}{dt} \\ \emptyset &= k_1 i \\ T &= k_2\,\emptyset \\ T(t) &= J\,\frac{d^2\theta}{dt} + b\,\frac{d\theta}{dt} \end{aligned}\right\} \quad (11)$$

In this context, J is the aggregate inertia of both the motor armature and the load, and b corresponds to the overall friction coefficient. With zero initial conditions, the Laplace transform of the DC motor equations in (11) is obtained as follows:

$$\left.\begin{aligned} E(s) &= RI + L\,sI \\ \emptyset &= k_1 I \\ T &= k_2\,\emptyset \\ T(s) &= J\,s^2\theta + bs\theta \end{aligned}\right\} \quad (12)$$

The transfer function of the DC motor and the block diagram representation of the motor are described as follows:

$$T_{trans}(s) = \frac{\theta}{E} = \frac{k_1 k_2}{s(R+sL)(Js+b)} \quad (13)$$

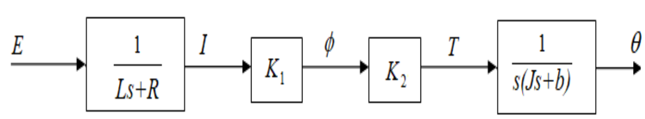

Fig. 2: Block diagram of DC motor.

where the DC motor specifications are chosen as: motor constant ($K_m = K_1\,K_2$) = 5000 N, friction $b = 20\,N.m.s/rad$, moments of the inertia $J = 1\,N.m.s^2/rad$, armature resistance $R = 1\,ohm$, and armature inductance; $L = 1m\,H$.

Also, every DC motor is connected with one gear. These two gears are connected between the DC motors and the ADRC controllers to smoothly move the antenna. The ratio of every gear is the relationship between the numbers of teeth that are connected with each other to create a move to the attached load. The gear ratio that is used in our design is chosen to be:

$$n = \frac{N_1}{N_2} = \frac{28}{45}$$

The complete block diagram representing the ADRC controller and the DC motor plant is presented in Figure 3.

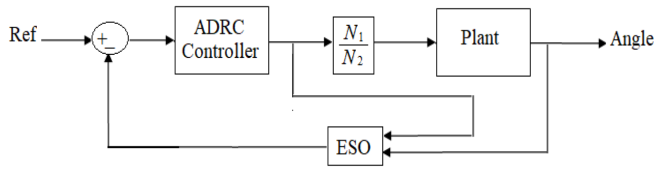

Fig. 3: Block diagram of ADRC controller design.

IV. Simulation Results

The proposed ADRC framework is demonstrated on a square multivariable system with two inputs and two outputs, showcasing its application in linear MIMO control. The DC motor commonly used in electrical and mechanical engineering as well as in process industries is adopted as the separation equipment. This controller design utilizes two inputs and two outputs. The two outputs are y_1 and y_2 which are the Azimuth angle and Elevation angle respectively. The antenna is moving towards the desired positions which are these two angles. The respective design or tuning parameters of each ADRC controller are chosen as follows: $b_{01} = b_{02} = 0.25,$, $\omega_{c2} = 5,$ $\omega_{01} = 2\omega_{c1}$, and $\omega_{02} = 4\ \omega_{c2}$. The desired positions of the Azimuth and Elevation angles are set as $\theta_1 = 40^{\circ}$and $\theta_2 = 60^{\circ}$; respectively.

The parabolic (or dish) antenna is used in this application design for verity of use in communications companies, military operations, and satellites identification.

The simulation framework is designed to provide simulation results in two case studies; without disturbances and with external disturbances.

A) Without Disturbances

In this simulation, we assume that there are no disturbances that can affect the performance of the results. The simulation results using the design of ADRC controller provide excellent results for the two ADRC controllers and the Azimuth and Elevation angles.

The first ADRC controller and the Azimuth angle, and the second ADRC controller and the Elevation angle results are shown in Figures 4 and 5; respectively. From the mentioned figures, we can see that the Azimuth angle reaches the desired position after almost *1.4 seconds*, and the Elevation angle settles at the position after *1.2 second*s. The errors in tracking under the application of ADRC for both outputs are converges to zero after few seconds. From this results, we conclude that the antenna (dish) is moving to the desired position pointing to the detected aim in a very short time.

B) With Disturbances

Here, we add external disturbances to the simulation design that affect the results and the antenna performance to set exactly at the desired position. We assume that there are natural disturbances such as wind, storm, and rain, …… etc. The chosen noise is white noise that can affect the performance of the results. It is shown that the simulation results can be affected by the disturbances, but it is still provides us very good results and lead the angles to the desired positions.

The first ADRC controller and the Azimuth angle, and the second ADRC controller and the Elevation angle results are shown in Figures 6 and 7, respectively. The tracking performance in terms of errors using ADRC for both outputs converge to zero after a few seconds with some oscillations. From the figures below, we can conclude that the Azimuth and the Elevation angles almost reach the desired positions after almost *0.75 seconds* with disturbances rate of *0.05%.* The antenna here is also moving fasters to the position where the goal is located. Also, because of the external disturbances that is unexpected sometimes, the antenna is still reaching the required position with very small error ration which doesn't affect the results.

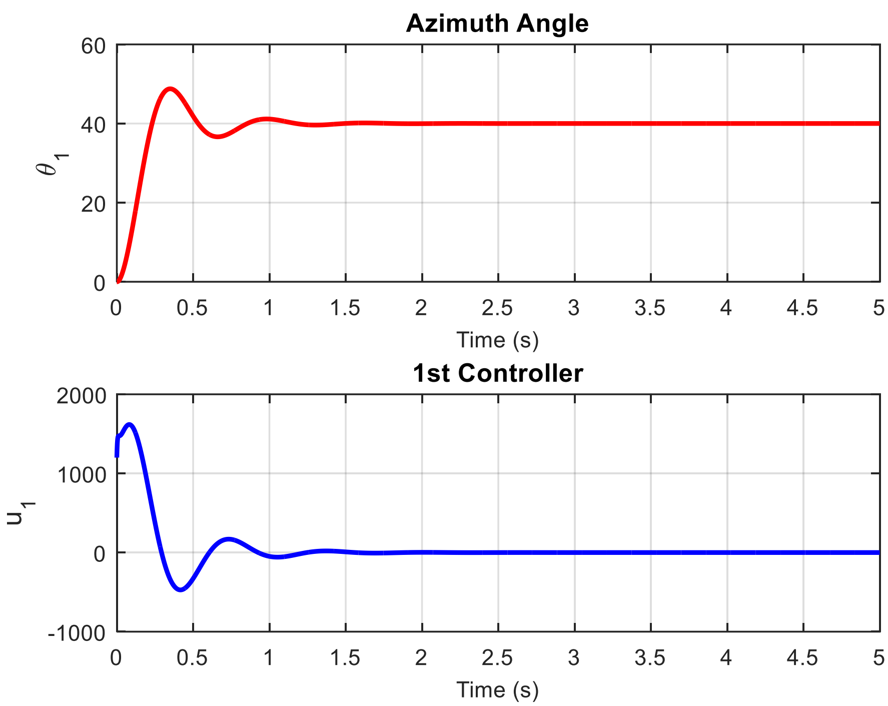

Fig. 4: Azimuth angle and 1st ADRC controller results without disturbances.

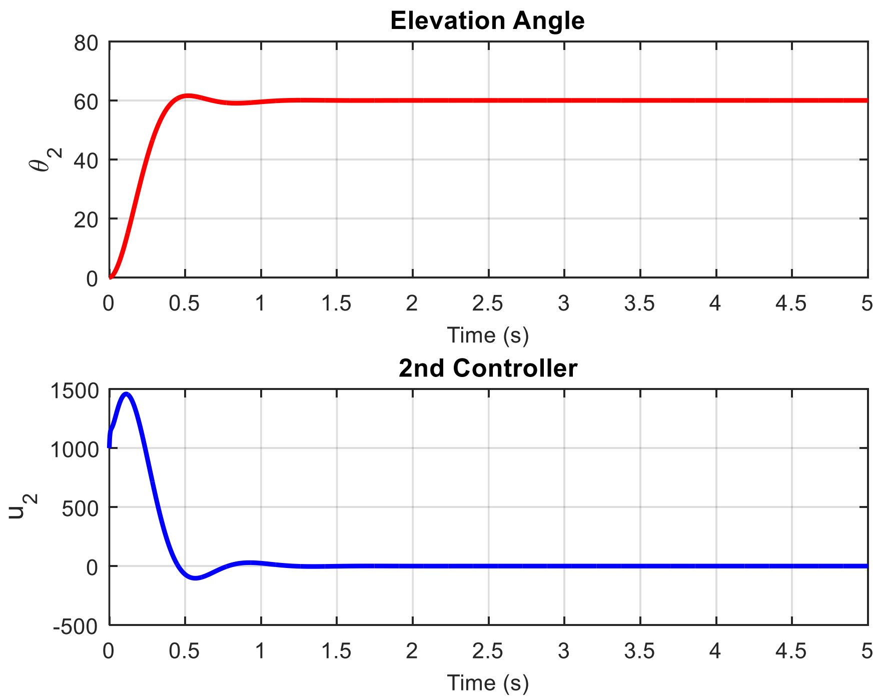

Fig. 5: Elevation angle and 2nd ADRC controller results without disturbances

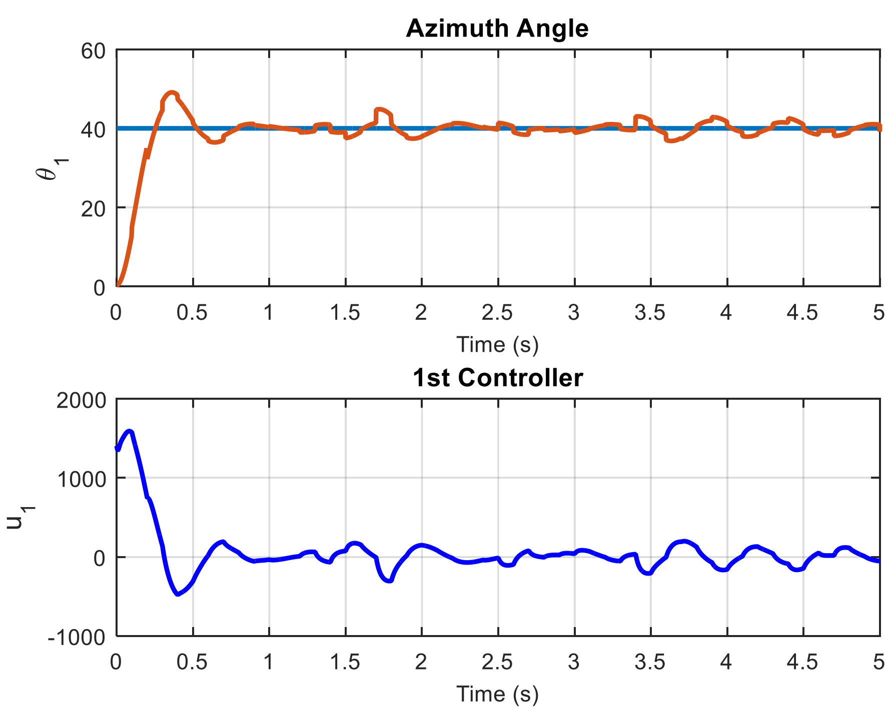

Fig. 6: Azimuth angle and 1st ADRC controller results with external disturbances

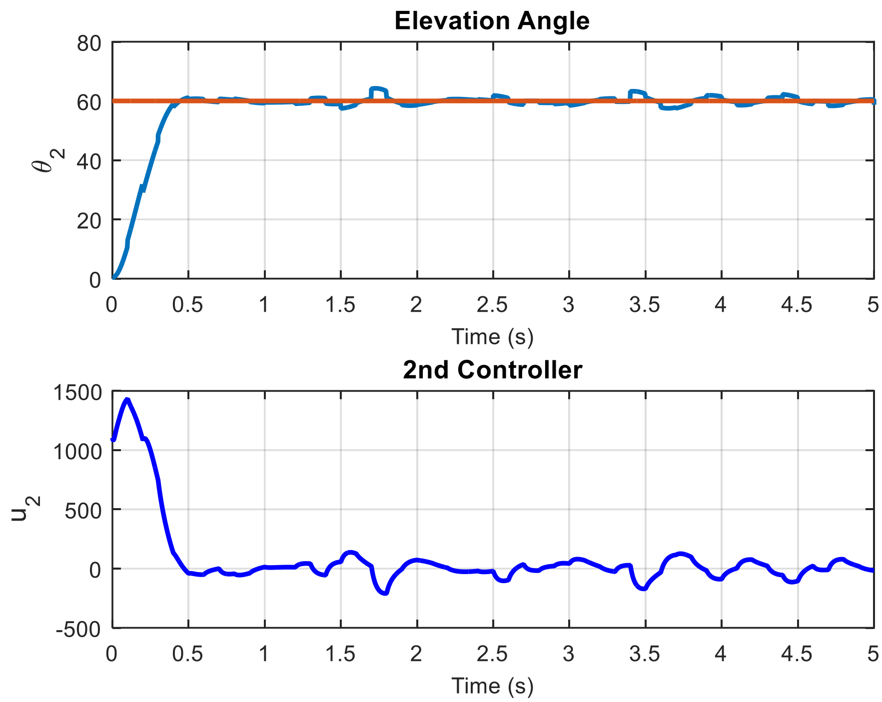

Fig. 7: Elevation angle and 2nd ADRC controller results with external disturbances.

V. Conclusion

In this paper, a novel ADRC-based dynamic decoupling control approach is proposed for a class of Multi-Input Multi-Output systems. The ADRC employs the ESO to decrease the phase lag and the internal and external unexpected disturbances. The proposed ADRC-based dynamic decoupling control approach is not easy to implement and design, but it is easy to understand. Once it is understood, it becomes clear to make it quite practical. The applied ADRC controller achieves better tracking performance because it tracks the angles to the exact positions in very short time. We can conclude from the results obtained that the controller is working very well in the absence of any noise or disturbances, and it drives the angles to the desired positions in a very short time. Similar to the design without disturbances, the controller with disturbances gives very good results and works perfectly with small oscillations that occur because of the external disturbances. These oscillations don't affect the results too much, and the angels can be driven to the desired positions in a very short time as well. After the results, we can say that even though the external disturbances, the angles and the ADRC controllers are still driven to the expected positions in less time (0.75 second) than the results without external disturbances. But overall, the results without affected disturbances are still better and the angles reach the desired positions smoothly and exactly in around 1 second. Simulation results on the proposed model demonstrate excellent performance in systems involving linear plants with significant uncertainties.

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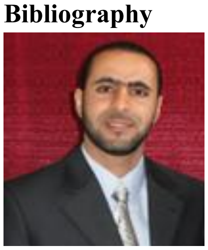

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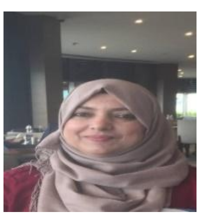

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