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DYNAMIC MODEL AND CONTROL OF 2-DOF ROBOTIC ARM

***Mesut HÜSEYİNOĞLU*[*1], *Tayfun ABUT*[2]**

[*1] Department of Mechanical Engineering, Dicle University, Diyarbakır, Turkey

[2] Department of Mechanical Engineering, Mus Alparslan University, Mus, Turkey

*Corresponding author; mesuth@dicle.edu.tr

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Robotic is a relatively young field of modern technology that exceeds traditional engineering boundaries. Control of the robots is important due to the fact that it has a usage area in many areas. In this study, modelling and control of two degrees of freedom (2-DOF) robotic arm were carried out. Lagrange-Euler method was used to obtain the dynamic equations of the robot. The system was controlled in the simulation environment. Sliding-Mode Control (SMC) and Proportional-Integral-Derivative (PID) control methods were proposed to control the 2 DOF robotic arm. The saturation function is used for the chattering problem of the sliding mode control method. Both process noise and measurement noise have been applied to control the robot in conditions close to the actual ambient conditions. The control methods applied according to the results of the simulation environment were compared and the results were examined.

Key words: *Sliding Mode Control, PID Control, Dynamic Model, 2-DOF Robotic Arm*

1. Introduction

Robotic applications are widely used in engineering and technology. It is well known that industrial robots are complex, dynamically coupled, high time-dependent and high nonlinear systems. These robots are commonly used in tasks such as welding, paint spraying, correct positioning systems, etc. In these tasks, the gripper of the robotic manipulators is required to move from one place to another or to follow certain trajectories as closely as possible. The motion control of robots is difficult due to uncertainties such as load changes, friction and external disturbances, and a highly non-linear mapped and time-varying system. Therefore, the trajectory tracking problem is the most important and fundamental task in the control of robot manipulators. Many methodologies and controllers in the literature [1-5] have been developed and implemented in order to maintain precise position control and stability in industrial robots. Hsu and Fu [6] proposed an adaptive decentralized controller for trajectory monitoring of robots. The controller cannot be fully designed for every robot joint as the control inputs and all robot connections are interconnected. Yang et al. [7] have added a disturbance monitor to the adaptive decentralized controller to compensate for the combined uncertainties for each joint. The limitation of the control system has been achieved by using only some special nonlinear damping terms. The fuzzy logic-based generalized prediction control structure is applied for a robotic arm in which a study fuzzy logic-based control algorithms are preferred [8]. A robust adaptive synchronization motion controller for a 2-DOF manipulator is proposed by Dou and Wang [9]. Yao et al. [10] developed a robust adaptive controller but neglected the effects of external disturbances and non-linear friction forces. Wijesoma [11] combined variable torque control and variable structure control to implement monitoring control. Mendes and Neto [12] introduce an adaptive fuzzy control that is integrated into a hybrid force/motion control system of an industrial robot to deal with a scenario of contact between the end-effector of the robot and a given surface. Although the improved controller has relatively high stability and robustness, the controller requires a high calculation load for practical application and cannot be used for trajectory monitoring control. He et al. [13] developed an adaptive controller based on artificial neural networks to address exogenous disorders and model uncertainties of an n-DOF robot manipulator. An adaptive neural impedance controller with input saturation was designed in [14] to satisfy the model uncertainties of a robotic manipulator. Nikdel et al. [15] developed an adaptive controller to improve the tracking performance of a robotic manipulator. The proposed controller also guarantees the system stability in the existence of nonlinearity and parameter uncertainties.

The main targets in designing robot control systems are stability and low tracking error. In this study, dynamic modelling and control of a 2-DOF robotic arm were carried out. Lagrange-Euler method [16] is used to obtain the dynamic equations. The Sliding-Mode Control (SMC) and Proportional-Integral-Derivative (PID) control methods are proposed to control the robotic arm. The control methods applied according to the results of the simulation environment were compared and their results were examined. In the next chapter, the dynamic model of the robotic arm is developed. Then, the controller design is demonstrated with numerical simulations. Finally, an overall evaluation of the results obtained is presented.

2. Dynamic model

The dynamic model is important as it is used in robot design, simulation and control. It is necessary to obtain the dynamic equations to implement high-performance controllers in the control of a robot. The robot which is considered in this study consists of 2 rotary joints. The dynamic model obtained by using Lagrange-Euler [16] method is given below in closed form.

$$M(q)[\ddot{q}]+C(q,\dot{q})[\dot{q}]+G(q)[q]=\tau-\tau_e \tag{1}$$

$$\tau_e = J^T F_{tot} \tag{2}$$

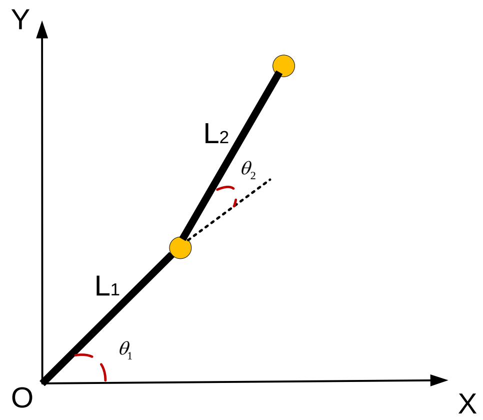

Figure 1. The model of the 2-DOF robotic arm

where, q, $\dot{q}$, $\ddot{q}$ and τ represent position, velocity, acceleration and control torque, respectively. $M(q) \in R^{3*3}$, $C(q) \in R^{3*3}$ and $G(q) \in R^{3*3}$ show inertial, forces of Coriolis-centrifugal and gravity matrices, respectively. τ_e represents the torque corresponding to the disturbing forces acting on the system from the environment. J shows the Jacobian matrix and F_{tot} shows the disturbing forces affecting the system. The model of the 2-DOF robotic arm is shown in Fig. 1.

3. Controller design

The SMC and PID control methods were used in the position control. These methods were used in various studies in the literature [17-18]. The aim of the control systems is that the output value of the system follows the reference value. The difference between reference and output values in the system is called the error value. Controllers are tried to minimize the error.

3.1. PID control

PID control method shows the best performance although it is an old method used in many control applications [19]. In Eq. (3), the fundamental mathematical expression of the PID method is seen [19].

$$u(t) = K_p e(t) + K_I \int_0^{\tau} e(t)\,dt + K_D \frac{d}{dt} e(t) \tag{3}$$

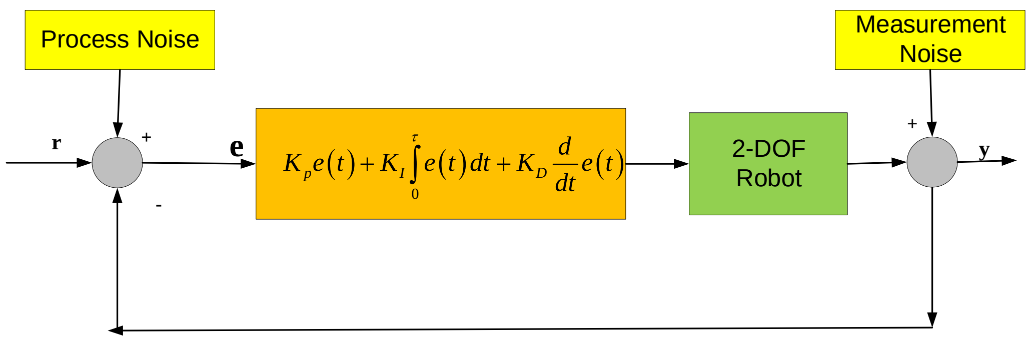

Figure 2. Block diagram of the PID feedback system

where, u, K_p, K_i, K_d and e are called the controller output, proportional gain, integral gain, differential gain and the error signal, respectively. Block diagram of the PID feedback system is shown in Fig. 2.

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Ziegler-Nichols method was used to find the PID coefficients and closed-loop control type was used in this study. The control parameters obtained by the Ziegler-Nichols method are given in T ab. 1.

Table 1. Control parameters obtained by the Ziegler-Nichols method

Control	K_P	K_i	K_D
P	0.5*K_{cr}	∞	0
PI	0.4*K_{cr}	0.8*P_{cr}	0
PID	0.6*K_{cr}	0.5*P_{cr}	0.125*P_{cr}

Each period of the output system oscillation and the maximum gain of the oscillation are shown P_{cr} and K_{cr}, respectively.

3.2. SMC method

SMC method which is used for the control of robots in various studies [20-23] was also used in this study. The joint angles of the robot were taken into account as the control variables of the system. The joint angles of the robot were checked in the presence of disturbing effects. Fig. 3 shows the block diagram of the SMC method.

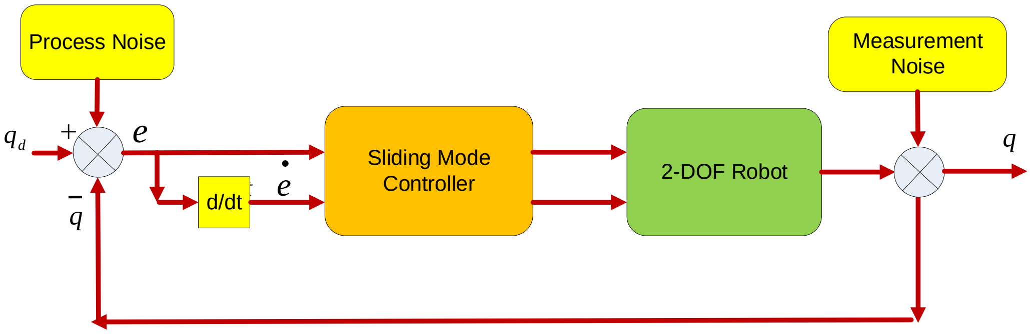

Figure 3. Control structure of the SMC method.

Error and time derivative of the error are given in Eq. (4) and Eq. (5), respectively.

$$e(t) = q_d(t) - q(t) \tag{4}$$

$$\dot{e}(t) = \omega_d(t) - \omega(t) \tag{5}$$

In the above equation, qd denotes the desired joint trajectory and q shows the true trajectory. The first and second degree derivatives were used for the Eq. (4).

$$S = \dot{e} - \lambda e \tag{6}$$

$$\dot{S} = \ddot{e} - \lambda \dot{e} \tag{7}$$

where, S represents the sliding surface and λ is a positive defined symmetric matrix, u control signal is given in Eq. 8. The concept of sliding surface is shown in Fig. 4.

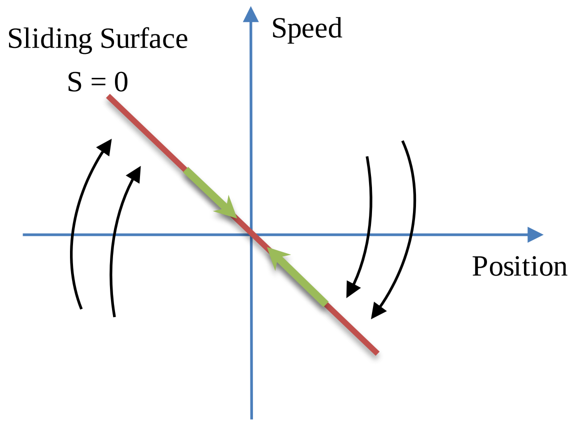

Figure 4. The concept of sliding surface.

$$u = -k \times sign(s)$$
$$sat(s/\phi) = \begin{cases} \dfrac{s}{\phi} & if \left|\dfrac{s}{\phi}\right| \le 1 \\ sign\left(\dfrac{s}{\phi}\right) & if \left|\dfrac{s}{\phi}\right| > 1 \end{cases} \tag{8}$$

Saturation function is used to solve the chattering problem, ϕ shows the thickness of the boundary layer, k is the constant parameter and *sign* is a signal function and s functions as a switch. Lyapunov criteria was used for the stability of the system.

4. Simulations

In this section, simulation studies were performed by using the dynamic equations and the performance values of the control methods are given graphically. The SMC and PID control methods are tested for their performance. Control variables are angles of θ_1 and θ_2 which are the basic axes of the 2-DOF robotic arm. The simulation run time was selected 30 seconds. Uncontrolled graphics of θ_1 and θ_2 are given in Fig. 5 and Fig. 6.

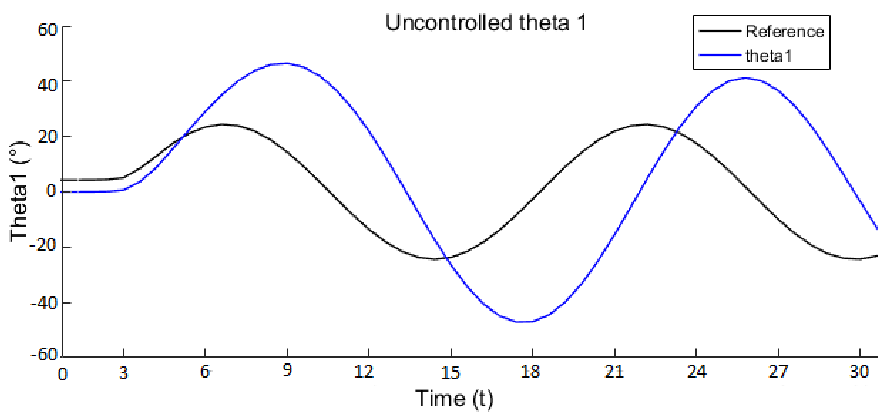

Figure 5. Uncontrolled graphic of θ_1

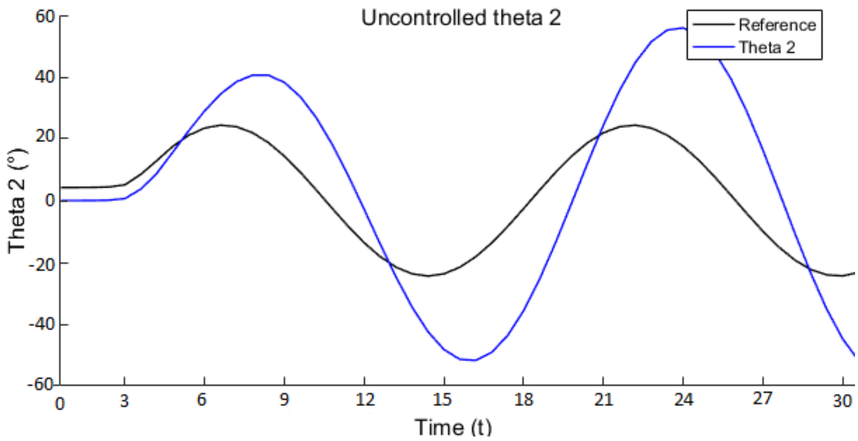

Figure 6. Uncontrolled graphic of θ_2

As seen in the Fig. 5 and Fig. 6, θ_1 and θ_2 don't follow the reference inputs. Responses of θ_1 and θ_2 belong to PID and SMC control methods and error graphics are shown in Figs. 7-14, respectively.

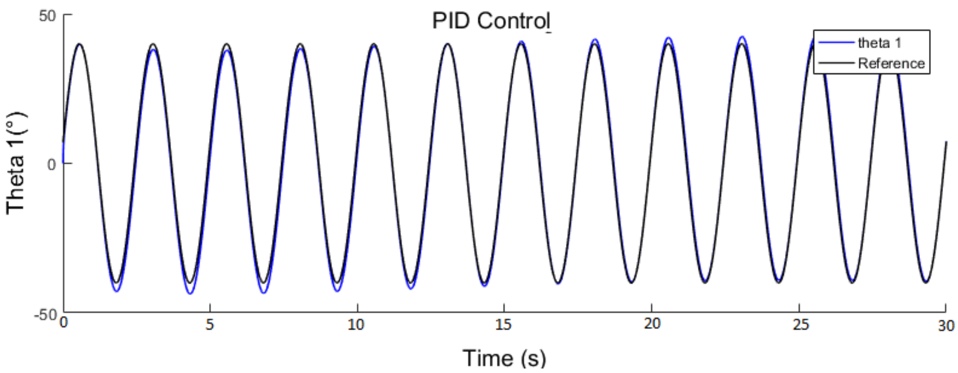

Figure 7. θ_1 angle response obtained through the PID control method

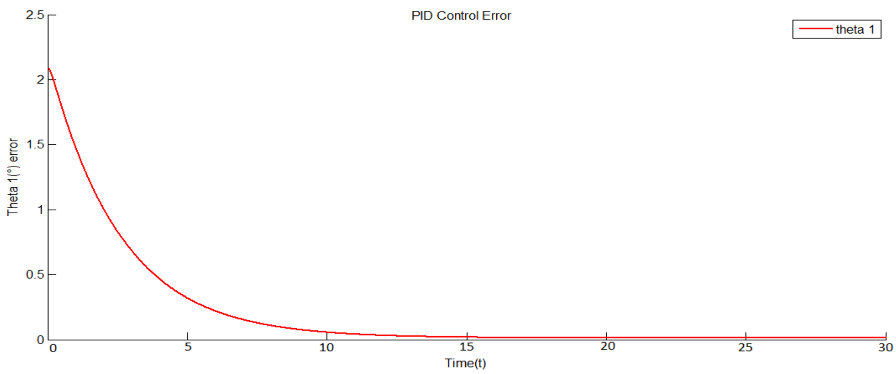

Figure 8. θ_1 angle error response obtained through the PID control method

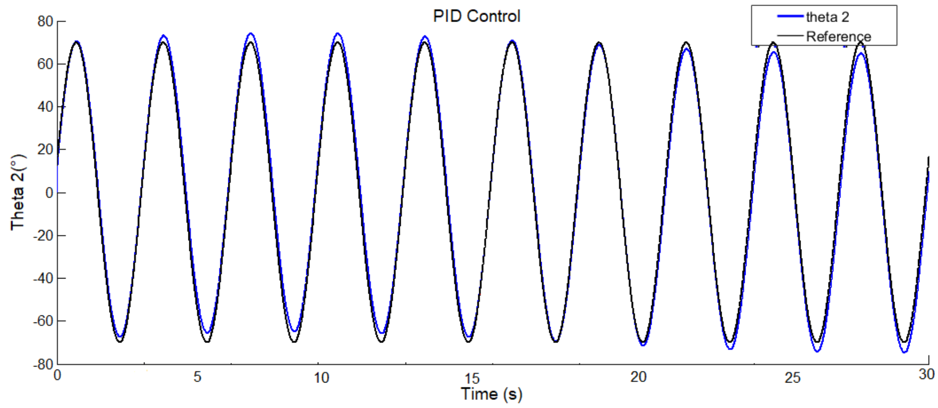

Figure 9. θ_2 **angle response obtained through the PID control method**

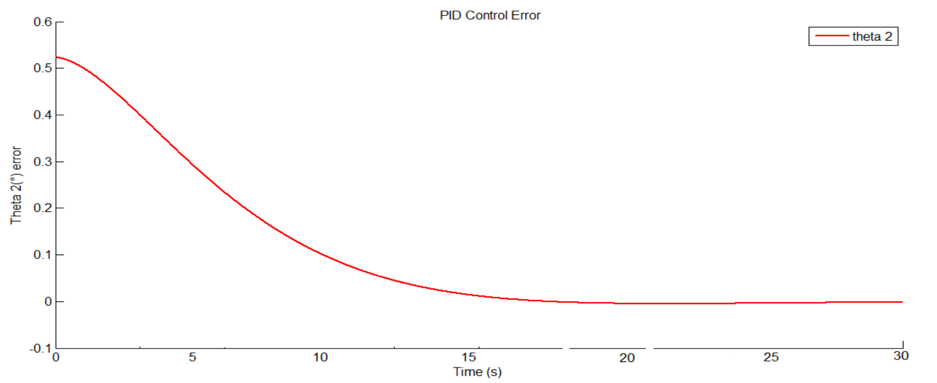

Figure 10. θ_2 **angle error response obtained through the PID control method**

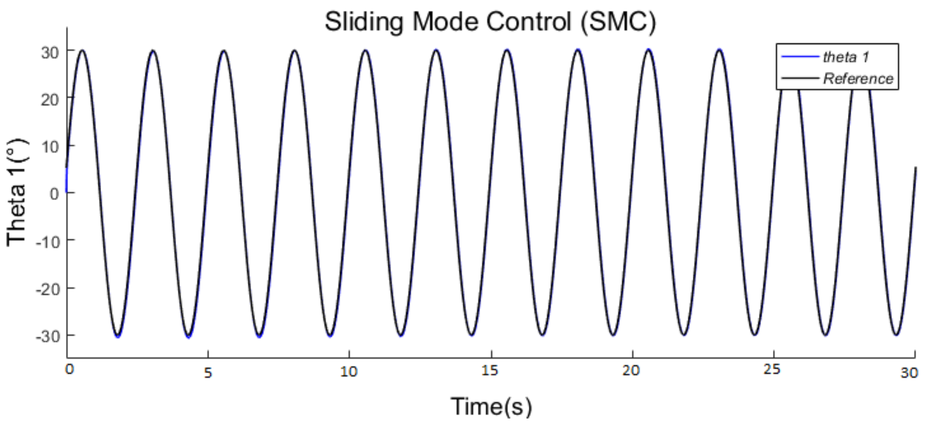

Figure 11. θ_1 **angle response obtained through the SMC method**

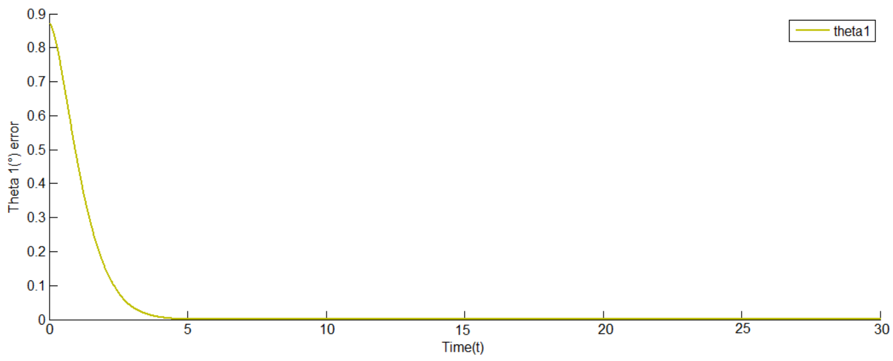

Figure 12. θ_1 **angle error response through the SMC method**

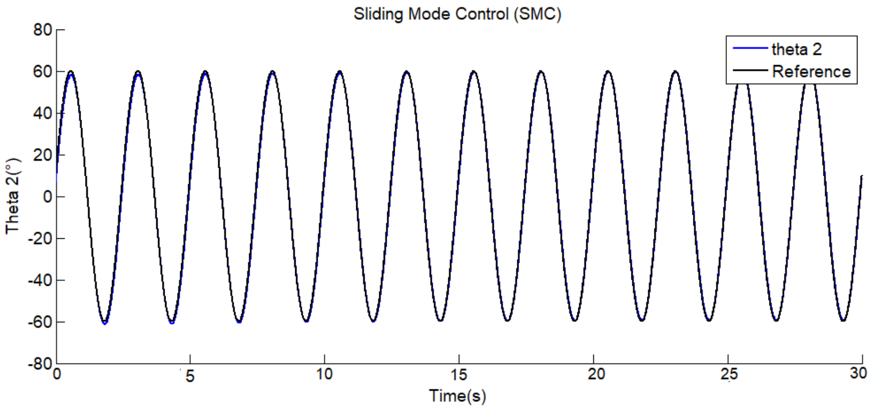

Figure 13. θ_2 angle response obtained through the SMC method

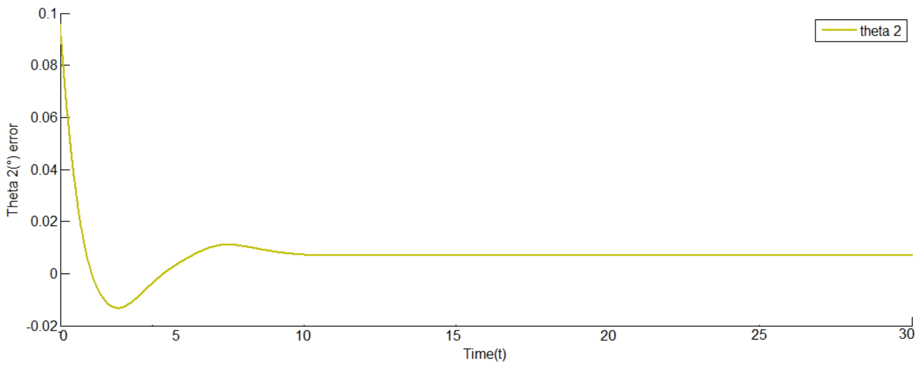

Figure 14. θ_2 angle error response obtained through the SMC method

Fig. 15 and Fig. 16 show the torque graphics required for the 1st joint and the 2nd joint.

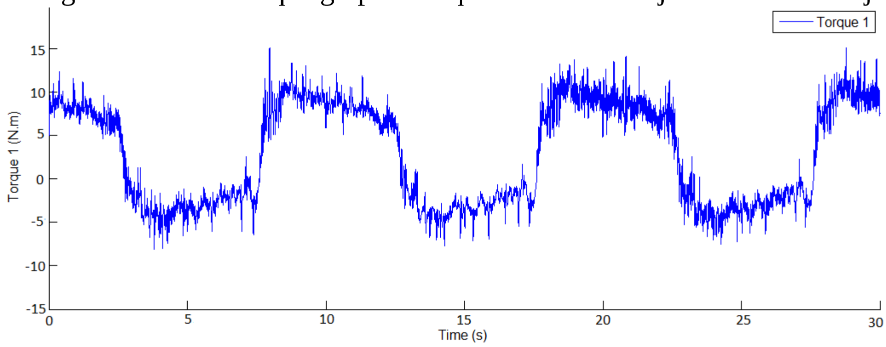

Figure 15. Torque graphic for θ_1 angle

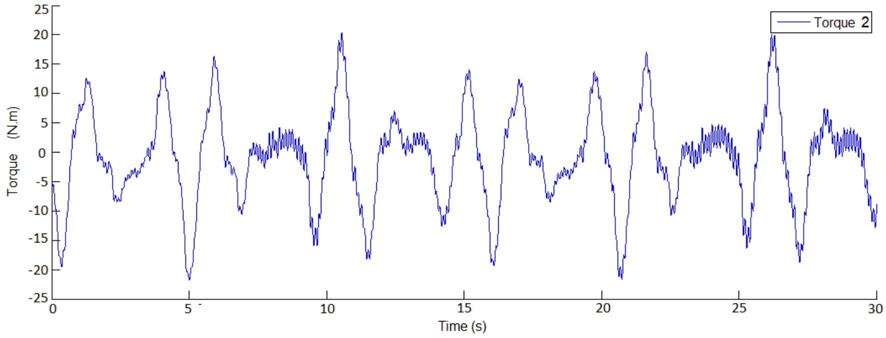

Figure 16. Torque graphic for θ_2 angle

As seen in figures, the PID control method generally followed the reference with greater amplitude. The PID control method has a greater settling time when considering error graphics. Similarly, as can be seen from the error graphs, SMC method gives good performance results according to PID control method.

5. Results and discussions

In this study, dynamic model of 2-DOF robotic arm was obtained by using Lagrange-Euler method. SMC and PID control methods were used for the control of the robotic arm. The performance of these control methods is shown in numerical studies that are performed in simulation environment. It has been seen that the chattering problem of SMC method is solved by saturation function. Both the signal noise and the measurement noise were applied to the signals in order to simulate the actual ambient conditions. A second order low pass filter is applied to increase the performance of the controllers in the noise environment. The cut-off frequency, damping ratio and initial run for the second order low pass filter are taken into account as 100 rad/s, 1 and 0, respectively.

As a result of the comparison of the control methods, it was observed that the controllers gave satisfactory results. The SMC method gave the best results. It is aimed to apply the proposed methods and a real system in future studies.

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