Design and Simulation of DC Motor Control Based on LQR and LQT for Optimal Control System

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ABSTRACT

This paper explains the system identification process in the context of using a DC motor. DC motors are one of the most common types of electric motors used in various industrial applications. This is due to the various advantages of DC motors, such as their simple structure, robustness, relatively affordable cost, and no complicated process in their operation. However, the main challenge discussed in this article is maintaining a constant motor speed, especially when there is a certain load change. Load changes can cause changes in motor response, even if a controller has been implemented. To overcome this, the optimization control techniques used are Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT). In this study, a DC Motor System Identification Module was developed with Arduino, which aims to facilitate the acquisition of DC motor models using first-order and second-order modeling methods. This module integrates Arduino and Simulink Matlab, which is used to collect input and output data needed in the system identification process. The result of this system identification is a DC motor model with an exogenous quadratic autoregressive (ARX) model. In addition, in the implementation of the LQR control technique, the parameter of the Q element matrix is generated by multiplying the system matrix C by the system matrix C. While the R element matrix is adjusted to the actual test of 0.0001. The experimental results show that the use of LQR control produces a more optimal system response time constant.

Keywords: DC Motor, Simulink, LQR, LQT

I.INTRODUCTION

To understand and analyze the characteristics of a system, system identification is needed. This system identification is done by performing mathematical modeling based on the properties of the system components. Through this identification, we can obtain a transfer function that represents the system. With this transfer function model, we can analyze the system's response to various different inputs[1][2].

With an understanding of the characteristics of the identified system, appropriate steps or solutions can be determined to keep the system operating as desired. System identification is an important experimental approach to determine the dynamic model of a system. This model is basically built on observational data[3][4][5].

The process of system identification is not simple and there are two main methods to obtain a mathematical model of a physical system, namely through analytical and experimental approaches. In the context of DC motors, there are several experimental techniques used to identify the system model. One of them is by observing the input and output data of the DC motor. However, some researchers have also used artificial intelligence algorithms such as recurrent neural networks (RNN) to model the dynamics of DC motors based on observation data [7][8].

Next, the use of voltage as an input variable and the rotational speed of the DC motor as an output variable is analyzed. The relationship between input and output is assessed using a system recognition tool integrated into the Matlab software[9].

It is important to note that DC motors often operate non-linearly, especially when there is a change in load. Therefore, conventional controllers such as PID controllers are commonly used because they provide good performance in controlling linear systems[10][11].

This study also reviews the control of induction motors using PID controllers and the Field Oriented Control (FOC) method. FOC is used to increase the torque current control signal in the PID system[12].

In addition, some researchers have implemented optimal control techniques, such as Linear Quadratic Regulator (LQR). In this paper, a permanent magnet DC motor is used as an installation to be determined and controlled using the LQR optimal control technique.

This research also involves the "black box" identification method, especially by monitoring the input-output of the DC motor system. In addition, a DC motor recognition module was developed using Arduino integrated with Simulink-Matlab software.

II.METHODOLOGY

1. Research Process

In the context of control systems, the system identification process typically follows the steps as shown in Figure 1. The system identification process consists of four main stages:

1. Availability of input-output data from the plant system to be identified.
2. Selection of the model structure to be used.
3. Estimate the appropriate model parameters.
4. Validation of the identified models, including the structure and values of the parameters used.

The system identification process can be described in a block diagram as shown in Figure 1.

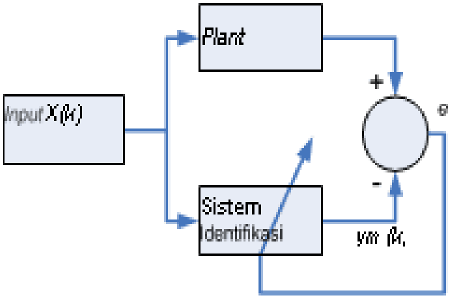


Figure 1. Block diagram of the identification process of a system.

In this study, the identification of the DC motor system was carried out in open loop mode using an Arduino device and a personal computer (PC) connected to the Simulink-Matlab device. The identification method applied is the static identification method.

The commonly used static identification method is to use the open loop method and provide step input, as shown in Figure 2.

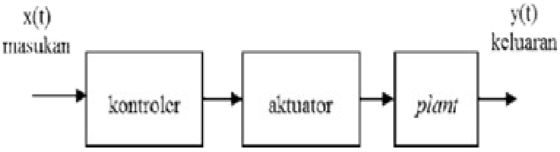


Figure 2. Block diagram of plant identification using the open loop method

Next, this study focuses on the system characteristics. System characteristics reflect the dynamic behavior of the system, and are often referred to as system performance specifications. The system output response appears after the input signal or test signal is given [14][15]. System response characteristics can be grouped into time response characteristics and frequency response characteristics. In this study, we focus on the time response characteristics of the DC motor [13].

The purpose of observing the time response characteristics is to understand how the system output response changes over time. In general, the specification of the time response performance can be divided into two stages of observation, namely the transient response specification and the steady state response [16]. Furthermore, the observation of the system characteristics can be approached with first-order and second-order system models.

2. Linear Quadratic Regulator

The best system is a system that can achieve optimal performance according to the given reference. To achieve optimal system control, optimization criteria are needed that are able to minimize the difference between the actual behavior of the system and the ideal behavior when the system experiences deviation.

This difference is measured through the performance index, which is an evaluation parameter that indicates the extent to which the system performance is in accordance with the desired. The performance index acts as a marker for optimal control, with lower performance index values indicating a more optimal system. In some cases, disturbances can cause changes in the controlled variable, and the controller must be able to compensate for these disturbances.

Linear Quadratic Regulator (LQR) is a technique used to design optimal control systems[17][18]. One of the advantages of the second-order optimal control method is its ability to systematically generate a state feedback gain matrix (K) for a system with m inputs (u). The control signal format can be described as follows:

$$(t) = -Kx(t) \quad (1)$$

With the form of its working index:

$$J = \int \infty [xTQx + uTRu] dt \quad (2)$$

Where:

Q = symmetric matrix, positive semi-definite, real (Q≥0).

R = symmetric matrix, positive definite, real (R>0).

The Q and R matrices play an important role in determining the error rate and energy consumption in this context. In this case, we assume that the control vector u(t) is infinite[19][20]. The linear control law contained in equation (1) is considered to be the optimal control law. The form of equation (1) is most appropriate when we have uncertainties in the elements of the K matrix and have determined the minimum number of preferences.

3. Linear Quadratic Tracking

The application of optimal control theory to linear systems has many applications in industry and education. This optimal control approach aims to reduce energy consumption by optimizing the energy function used, resulting in optimal performance. One application of this concept is in vehicle suspension systems, which aims to reduce the effects of shocks or disturbances when vehicles cross uneven roads.

One of the problems that is solved is the steady state error by using an integral controller. The integral controller works by calculating the integral output error as an additional state variable in the system.

The purpose of the control in this study is to control the position of the vehicle through its suspension system in such a way that the vehicle remains in the desired position with a minimum steady state error rate when shocks or disturbances occur. The use of the controller in this study is the Linear Quadratic Integral Tracking (LQIT) method, which is a modification of the Linear Quadratic Tracking (LQT) controller with the addition of an integral controller.

Linear Quadratic Regulator (LQR) is an optimal control method in linear systems with quadratic criteria used to solve regulator problems. While Linear Quadratic Tracking (LQT) is an optimal control method in linear systems with quadratic criteria used to solve tracking problems. The general system state equation is represented in a form that describes the relationship between various variables in the system.

$$x = Ax + Bu \tag{3}$$

$$y = Cx \tag{4}$$

With,

$x_{n*1} = State\,system$

$U_{m*n} = State\,input$

$y_{1*1} = State\,output$

A = System matrix

B = System matrix

C = Output matrix

By minimizing the energy (cost function/quadratic function) through the performance index in the interval [t_0,∞]:

$$J = \frac{1}{2}\int_{t_0}^{\infty} \left(e^T Q e + u^T R u\right) dt \tag{5}$$

With

t0 = initial time

∞ = end time

Q = positive semidefinite matrix

R = positive definite matrix

The regulator and tracking problems can be overcome or solved using the Riccati Equation as follows:

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \tag{6}$$

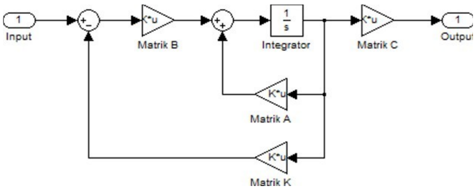


Figure 3. LQR circuit

In designing LQR and LQT controllers, the selection of the weight matrix is an important key. The larger the Q value, the closer the system is to its minimum point, resulting in minimal energy consumption. The optimal control block diagram can be seen in Figure 1. The main goal is to ensure that the value of the Riccati

Equation solution becomes a matrix that has a small value, such as:

$$K = R^{-1} B^{T} P \tag{7}$$

$$u = -Kx \tag{8}$$

III.RESULTS AND DISCUSSION

1. Simulation Circuit

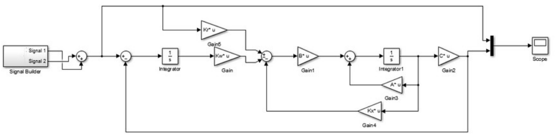
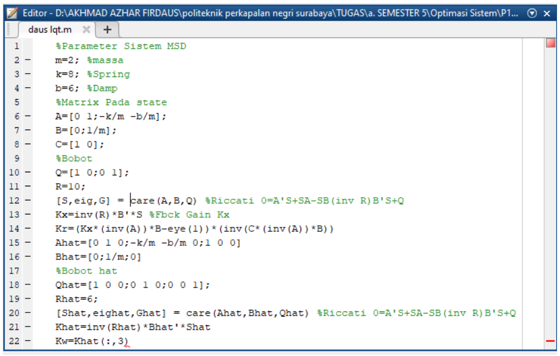


Figure 4. LQR Simulation Circuit

2. Script



```
%Parameter Sistem MSD
m=2; %massa
k=8; %Spring
b=6; %Damp
%Matrix Pada state
A=[0 1;-k/m -b/m];
B=[0;1/m];
C=[1 0];
%Bobot
Q=[1 0;0 1];
R=10;
[S,eig,G] = care(A,B,Q) %Riccati 0=A'S+SA-SB(inv R)B'S+Q
Kx=inv(R)*B'*S %Fbck Gain Kx
Kr=(Kx*(inv(A))*B-eye(1))*(inv(C*(inv(A))*B))
Ahat=[0 1 0;-k/m -b/m 0;1 0 0]
Bhat=[0;1/m;0]
%Bobot hat
Qhat=[1 0 0;0 1 0;0 0 1];
Rhat=6;
[Shat,eighat,Ghat] = care(Ahat,Bhat,Qhat) %Riccati 0=A'S+SA-SB(inv R)B'S+Q
Khat=inv(Rhat)*Bhat'*Shat
Kw=Khat(:,3)
```

Figure 5. LQR script

3.Simulation Results

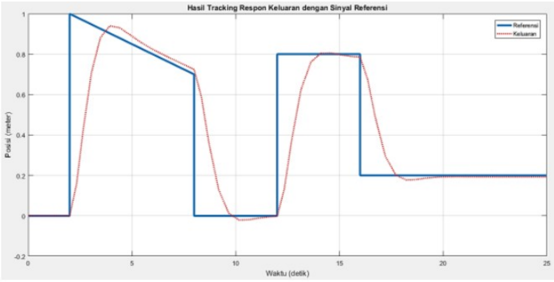


Figure 6. LQT graph

4.Analysis

The controller testing applied to the system was carried out under various conditions, assuming that the disturbance or shock to the suspension system varies. In the simulation results, the blue line illustrates the reference value that has been set, while the red line illustrates the system response with the LQIT controller. Based on the test results, it is known that the system with the LQIT controller is able to track the position according to the specified reference. In the transient response of the system, it was found that the steady state error value was 3%. This value indicates good conditions, with an average steady state error of 3%. This indicates that when there is a shock to the vehicle that causes a change in position in the suspension system, the applied controller is able to bring the suspension system to track the position precisely, so that the disturbance or shock that occurs can be dampened properly.

IV.CONCLUSION

Based on the results of the test simulation, it can be concluded that the application of the Linear Quadratic Integral Tracking (LQIT) controller to a simple suspension system consisting of mass, springs, and dampers is able to overcome disturbances or shocks. This system is able to track references well and has an average steady state error value of 3%.

V.CLOSING

1.Awards

The researchers realized that creating a magazine that serves the community would be difficult to achieve without the help and support of many stakeholders.

Therefore, on this occasion, the researcher would like to express his sincere gratitude to all parties who have participated and contributed to this project.

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