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Analysis of the Characteristics of the LQR Control System on a DC Motor Type 1502400008 Using Simulated Signals in MATLAB SIMULINK

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Abstract

This study aims to analyze the characteristics of the control system Linear Quadratic Regulator LQR and Linear Quadratic Tracking LQT on DC motor type 1502400008 using simulation on MATLAB SIMULINK, in this study will use the Multi Antenna Types signal system namely SISO, SIMO, MISO and MIMO which will implemented on a DC motor, before collecting data the first thing to do is look for a DC motor Data Sheet and with these data we can make a mathematical model of a DC motor in the form of a Transfer Function, after creating a Transfer Function model continue to make a simulation modeling in MATLAB SIMULINK, the data taken is comparative data for each control system and a comparison of the control systems that have been paired with the LQT and LQR systems, after collecting all the data an analysis and comparison of the results of the SISO, SIMO, MISO and MIMO signal control systems will be carried out. The expected results of this study are an understanding of the differences between the control systems of the Linear Quadratic Regulator LQR and Linear Quadratic Tracking LQT and being able to analyze the characteristics generated using the Multi Antenna Types signal system.

Keywords: MATLAB SIMULINK, Linear Quadratic Regulator, Linear Quadratic Tracking, signal control Multi Antenna Types.

1. Introduction

In electrical power generation, voltage stability is a critical factor because it directly influences the overall power system. Voltage instability can cause disruptions in the entire power system, particularly affecting the quality and reliability of power delivery from the generator to consumers. In the worst-case scenario, voltage instability may lead to load shedding mechanisms. Practically, the stability of the system is determined by the stability of the voltage regulation system, which is managed by the excitation system in generators and integrated control circuits within the system (Rahman et al., 2024). In electric motor control systems, numerous disturbances can occur, requiring dynamic stability studies around the operating point. Thus, an analysis of the stability behavior of an electric motor control system is necessary, and this paper focuses on using Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods to perform the analysis (Sutanto, 2020; Nugraha et al, 2022; Nugraha et al., 2019).

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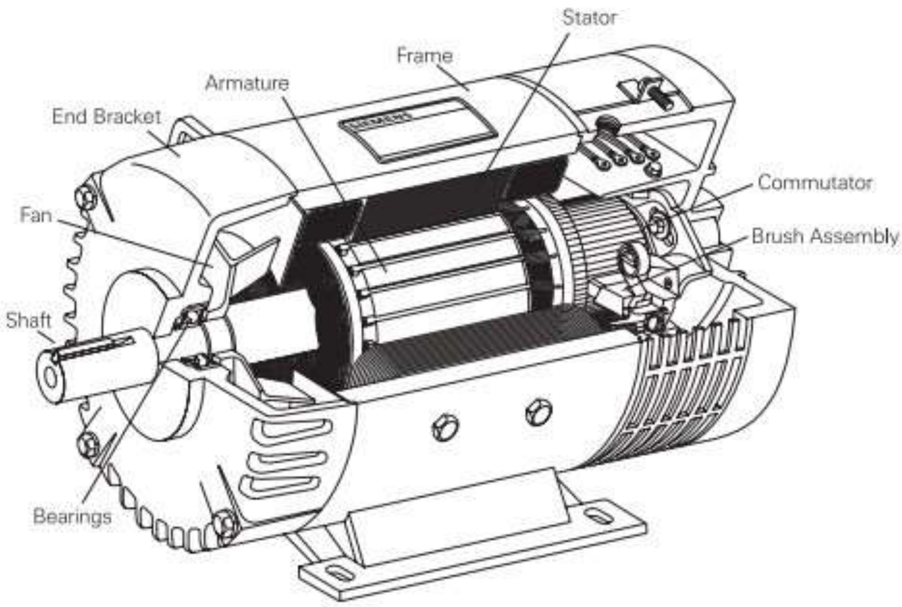

figure 1. contruction Motor DC

To better understand this study, we first need to explore the characteristics of DC motors. A DC motor is commonly used as a driving force in electric vehicles because of its controllable speed and wide speed variation. The main components of a DC motor include the main field winding (stator) and the rotating winding (armature or rotor) (Mu'in et al., 2023). Understanding these components is vital as it helps in comprehending the various functions of the DC drive. The relationship between these electrical components is illustrated in the diagram. In small DC motors, the field may be a permanent magnet, but in larger DC motors, it is typically an electromagnet. The field winding and pole piece are attached to the frame, with the armature placed between the field windings (Khadkikar & Chandel, 2019; Sharma et al., 2017; Chauhan & Ghosh, 2018).

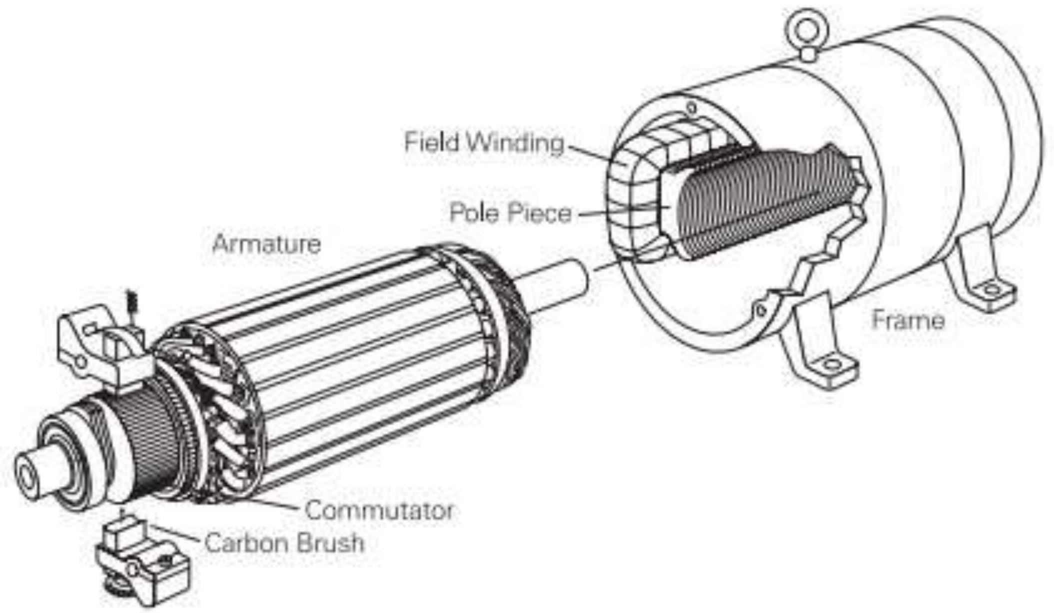

Figure 2. Rotor Motor DC

The principle of operation of a DC motor involves the interaction of the magnetic fields created by the armature and the stator. The stator remains static, while the rotor rotates when current flows through the armature windings (Amrullah et al., 2023). As the current reverses direction, the polarity of the armature windings is switched, causing the rotor to continue rotating. This process ensures continuous motion and is essential for understanding the mechanical operation of the motor. This alternating interaction between the magnetic fields in the stator and rotor is what drives the motor (Hammad et al., 2017; Lee et al., 2020; Ayyappan et al., 2021).

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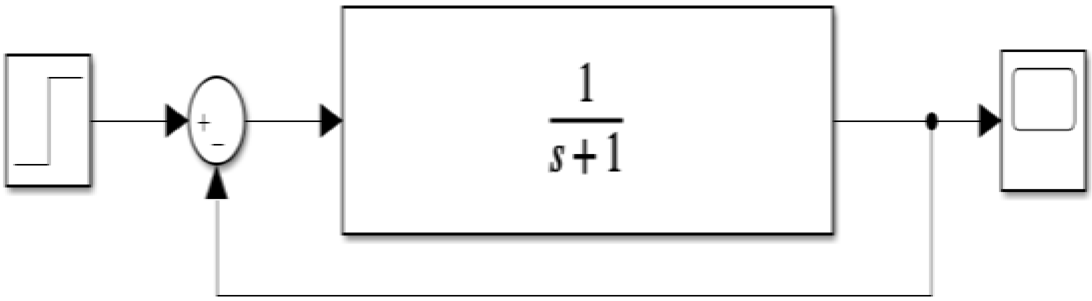

Figure 3. signal SISO

In addition to the motor's functionality, it is also important to understand the types of signals used in multi-antenna systems. One such signal type is SISO (Single Input Single Output), which represents a standard radio channel where both the transmitter and receiver use a single antenna. While this system is simple and does not require complex processing, its performance is limited by interference and fading (Pangestu et al., 2024). To overcome these limitations, systems like SIMO (Single Input Multiple Output) and MISO (Multiple Input Single Output) are used. SIMO uses multiple receiving antennas to combat fading, while MISO involves transmitting the same data from two antennas to improve signal reception. These systems provide better performance by utilizing diversity and redundancy (Wang & Chen, 2019; Yang et al., 2017; Zafar et al., 2018).

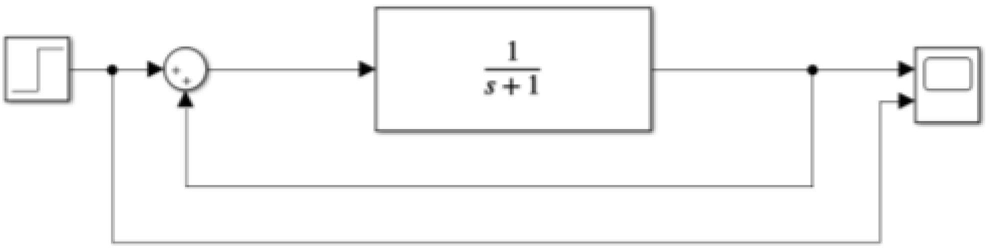

figure 4. signal SIMO

Finally, MIMO (Multiple Input Multiple Output) systems utilize the natural phenomenon of multipath propagation, where signals reflect off various surfaces and reach the receiver at different angles and times. This method, using multiple transmitters and receivers, improves performance and range by enabling the combination of multiple data streams. MIMO systems enhance signal reception by utilizing spatial diversity, which allows for better use of the available antenna resources and increases the system's reach (Tian et al., 2020; Li et al., 2021; Zhang et al., 2019).

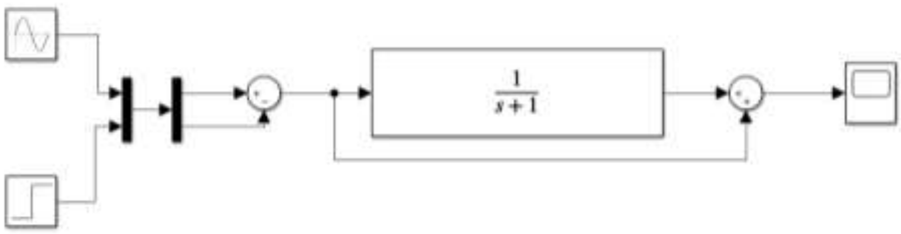

Figure 5.signal MISO

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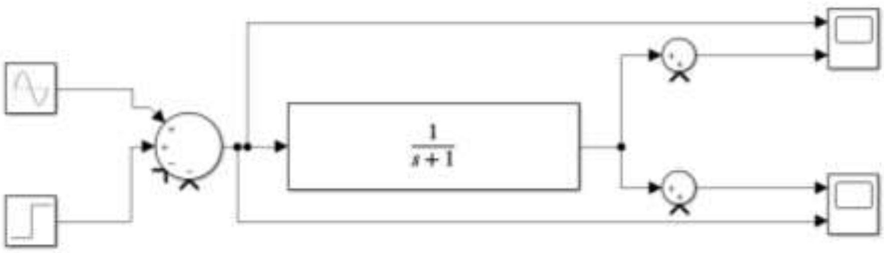

Figure 6. signal MIMO

Optimal control methods in state-space-based systems are used to achieve the desired control action. The Linear Quadratic Regulator (LQR) controller has two parameters: the weight matrices Q and R, which must be determined to produce optimal control actions. Unlike the Proportional-Integral-Derivative (PID) controller, which has systematic tuning methods like Ziegler-Nichols and Cohen-Coon, the LQR controller does not have a specific systematic tuning method for determining the Q and R matrices. This paper proposes a solution for determining the LQR controller design parameters using the latest metaheuristic algorithm, Stochastic Fractal Search (SFS). The SFS algorithm is inspired by natural growth phenomena with a mathematical concept called fractals. By utilizing the stochastic diffusion properties of fractals, the particles can effectively and efficiently explore and exploit the search space. The proposed LQR controller optimization using the SFS algorithm was applied to an unmanned vehicle (quadrotor) model with 12 state variables. The simulation results show that after only 100 iterations, the quadrotor's position can be well controlled, allowing it to follow the set-point changes satisfactorily. Optimal control has been widely used in various fields, such as industry, robotics, and other engineering areas. The advantage of this method is that it provides an optimal solution for system control problems defined in state-space. As it is state-space-based, the LQR method can efficiently solve control problems in signal systems.

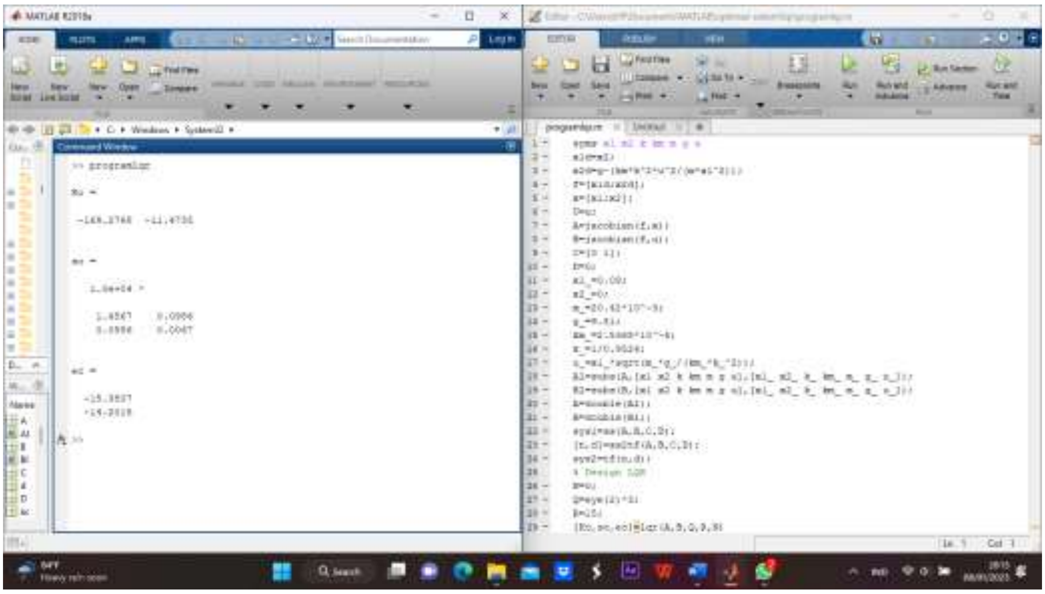

Figure 7. Coding LQR

After understanding DC motors and Multi Antenna Types signals, we also need to understand MATLAB software. MATLAB is a computational programming and analysis software widely used in all areas of mathematics applications, including education and research at universities and industries. With MATLAB, complex mathematical calculations can be implemented more easily in the program, and Simulink, an add-on part of MATLAB (Mathworks Inc.), can be used as a modeling, simulation, and analysis tool for dynamic systems using a graphical user interface (GUI).

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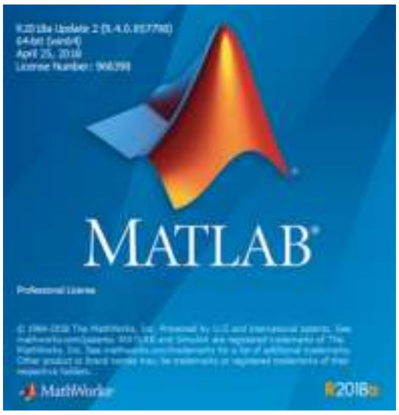

Figure 8. Software MATLAB

2. Material and methods

2.1. research stage

The first step that must be done before carrying out this research in detail is to look for a DC motor datasheet, here I got a DC motor datasheet with type 1502400008 24V diameter 42mm to be used as the object of analysis this time

DC motor datasheet as follows:

Table 1. data sheet motor dc

Nominal Voltage	24Vdc	
Body Diameter	42mm	
RS stock no.	225-5410	
Assembly Data	Units	Value
Nominal speed	RPM	3070
Torque	mNm	70
Output power	W	22
Input Power, No load	W	4,3
Input Current, No load	A	0,18
Protection rating		IP20
Max usable power	W	31
Start torque	mNm	298
Start current	A	6,16
Resistance	Ω	3,9
Inductance	mH	9,35
Weight	g	200
Life	h	2000
Ratio		62.5:1

.

Once we have data from a DC motor, we can apply a mathematical approach to the data and find the transfer function using the Laplace method for both first-order and second-order systems.

1. First-Order Transfer Function

The first-order transfer function is given by:

$$\frac{C(s)}{R(s)} = \frac{1}{Ts+1}\frac{1}{s}$$

For the first-order calculation from the experiment, we use parameters such as torque and current as follows:

$$C(s) = \frac{1}{s} - \frac{T}{Ts+1} = \frac{1}{s} - \frac{1}{s+(\frac{1}{T})}$$

Where kk is given by:

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$$G(s) = G(s) = \frac{k}{\tau s+k}$$

Thus, the first-order transfer function is:

$$K = \frac{\tau}{is} = \frac{0,07}{0.18} = 0.38888$$

$$\mathrm{G(s)} = \frac{0.38888}{0.07+0.38888}$$

Where:

- τ\tau = friction torque (N·m)
- ii = load current (A)

2. Second-Order Transfer Function

The second-order transfer function is given by:

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + \zeta\omega_n s + \omega_n^2}$$

Where ζ\zeta is the damping ratio and ωn\omega_n is the natural frequency of the system. Unlike the first-order system, the second-order system response exhibits an overshoot. Overshoot occurs when the damping ratio is less than unity, leading to an underdamped response.

MATLAB Coding for LQR Input

Next, we need to write a MATLAB code to get the values that can serve as inputs to the LQR (Linear Quadratic Regulator), so that LQR can produce the desired output. The following code performs the necessary calculations:

```
syms x1 x2 k km m g u
x1d = x2;
x2d = g - (km * k^2 * u^2 / (m * x1^2));
f = [x1d; x2d];
x = [x1; x2];
U = u;
A = jacobian(f, x);
B = jacobian(f, u);
C = [0 1];
D = 0;

x1_ = 0.09;
x2_ = 0;
m_ = 20.42 * 10^-3;
g_ = 9.81;
km_ = 2.5365 * 10^-5;
k_ = 1 / 0.9524;
u_ = x1_ * sqrt(m_ * g_ / (km_ * k_^2));

Al = subs(A, [x1 x2 k km m g u], [x1_ x2_ k_ km_ m_ g_ u_]);
Bl = subs(B, [x1 x2 k km m g u], [x1_ x2_ k_ km_ m_ g_ u_]);

A = double(Al);
B = double(Bl);

sys1 = ss(A, B, C, D);
[n, d] = ss2tf(A, B, C, D);
sys2 = tf(n, d);

% Design LQR
N = 0;
Q = eye(2) * 3;
R = 15;
[Kc, sc, ec] = lqr(A, B, Q, R, N);
```

The output from the code is as follows:

```
Kc =
 -169.2768  -11.4735

sc =
```

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```
  1.0e+04 *
   1.4567    0.0986
   0.0986    0.0067

ec =
 -15.3507
 -14.2015
```

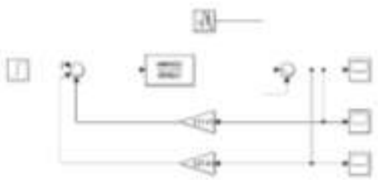
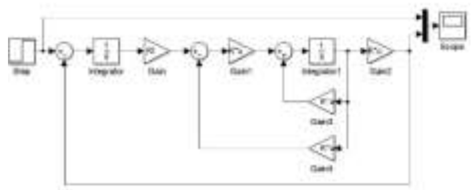
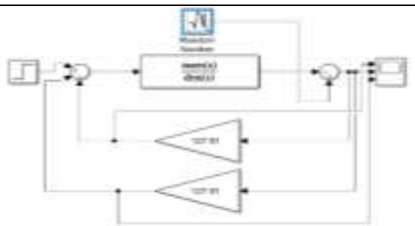
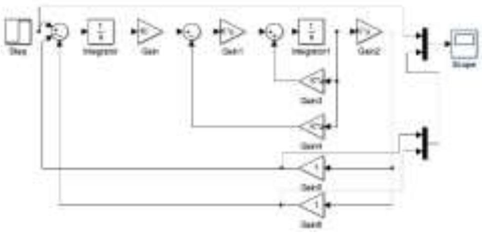
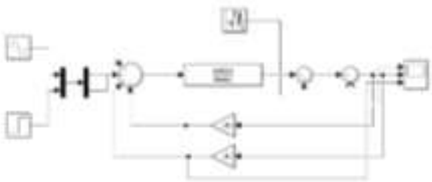
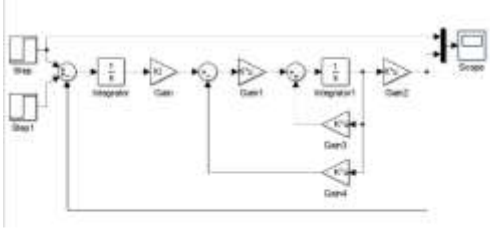
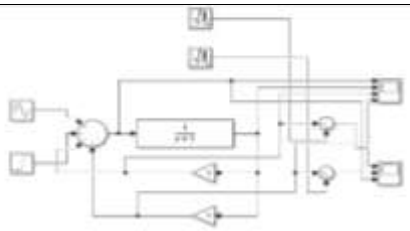
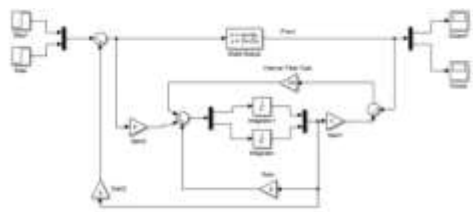
These results can be used as inputs for the LQR system, where these values can be entered into the gain blocks in Simulink in MATLAB.

This translation provides a clear and technical explanation of how to determine and implement transfer functions for a DC motor and design an LQR controller using MATLAB.

2.2. Simulation data

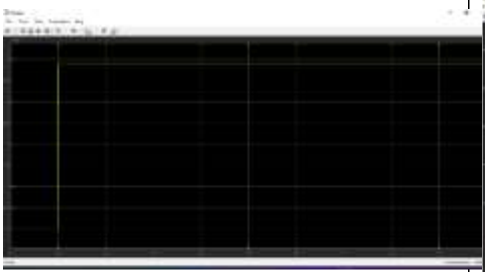
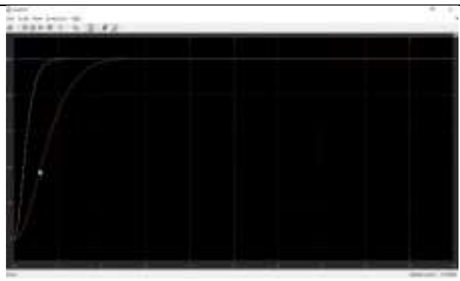
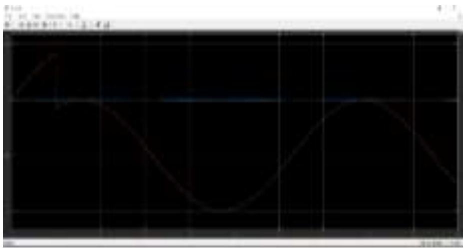
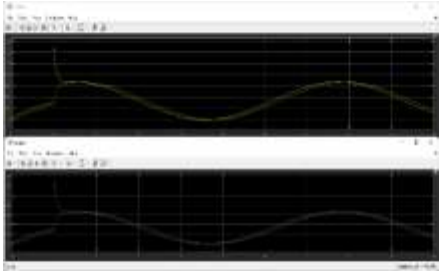
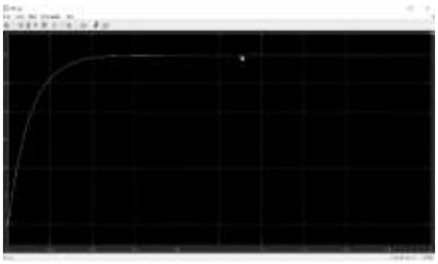
After getting the first order calculation data and getting the coding results from the LQR and assembling the LQR series, analysis is then carried out using MATLAB SIMULINK for each type of control system. Use comparison data when the system does not use LQR and when it uses LQR.

Table 1. wiring

system Signal	Simuation circuit without LQR	Simuation circuit with LQR
SISO		
SIMO		
MISO		
MIMO		

3. Results and discussion

Table 2. Result simulation

Result Trial		
System Signal	Without LQR	With LQR
SISO		
SIMO		
MISO		
MIMO		

Based on the analysis results shown in the table, it can be concluded that the optimal outcome using the LQR method achieves the most efficient motor balancing response according to the specified criteria, as reflected in the values of the matrix. In certain processes, the controlled variables may experience deviations due to disturbances. A control regulator is designed to compensate for such disturbances. Linear Quadratic Control (LQR) is one of the methods for designing optimal control systems. The plant is assumed to be linear and represented in state-space form, with the objective function being a quadratic function of the plant's state and the control input signal.

The LQR method is effective in providing optimal solutions for various control problems due to its ability to balance system performance and disturbance compensation. The approach involves determining the best set of control gains that minimize the cost function, which includes both the plant's state and the control effort. By using LQR, the system can maintain its desired performance even in the presence of external disturbances.

One of the main advantages of the Linear Quadratic formulation is its ease of analysis and implementation. Unlike other control methods, LQR provides a straightforward approach to designing controllers by solving a set of algebraic Riccati equations. This simplifies the process of tuning the controller and adjusting it to achieve the desired system performance.

The Linear Quadratic method is widely used to solve various control problems, including those involving time minimization and optimal performance under constraints. It is particularly beneficial in systems where the goal is to minimize the impact of disturbances while maintaining stability and optimality. The simplicity and effectiveness of the LQR method make it a popular choice in many engineering applications.

In conclusion, the use of the LQR method offers significant benefits in terms of system performance and disturbance rejection. Its ability to provide optimal control solutions while maintaining stability and meeting design criteria makes it a powerful tool in control system design. The method’s ease of analysis and implementation further contribute to its widespread use in practical applications across various fields.

4. Conclusion

An alternative LQR controller design technique has been developed in this study. The developed LQR method was then applied to control an electric motor model. The simulation results show that the Quadrotor is able to follow several set-point changes with excellent performance. The selection of the Q and R weight matrices in this thesis was done through a trial-and-error approach, which took considerable time to achieve the desired results. Therefore, it is necessary to develop a more efficient method to determine the values of the Q and R matrices.

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