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Analysis of Circuit with LQR and LQT Control Systems on DC Motor Type C34-L70 with Noise

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Abstract

The rapid advancement of technology to meet various human needs has significantly facilitated various aspects of daily life, including industrial processes. One notable technological innovation in this regard is the DC motor, which serves as a critical actuator in numerous industrial applications. DC motors are valued for their simplicity, precision, and controllability, making them essential in automation, robotics, and other mechanical systems. However, despite their advantages, a common challenge encountered with DC motors is the inability of the output to consistently reach the desired target or setpoint. This issue is often attributed to various factors such as system instability, external disturbances, and the limitations of the control methods used. To mitigate these challenges, system optimization strategies are implemented to improve the performance of DC motors and ensure they can achieve precise and reliable outputs. System optimization is vital in overcoming the inherent limitations of DC motors, particularly when external factors, such as noise, affect the system's performance. Noise, or external disturbances, can significantly impact the output of a DC motor, causing fluctuations and reducing its efficiency. To address these issues, various control techniques, such as Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) controllers, have been explored in this paper. These methods are designed to stabilize the motor's performance by minimizing errors between the actual output and the desired setpoint. LQR and LQT are advanced control strategies that help optimize the system by adjusting control inputs to achieve better performance, particularly in environments with high levels of disturbance or noise. In this study, noise is introduced into the DC motor system using different circuits, and its effects on the output are carefully analyzed. The noise is applied to each output through various configurations, and the resulting disturbances are evaluated to understand their impact on the motor's performance. The findings from these experiments are crucial in identifying the specific factors that influence the motor's behavior under noisy conditions. The goal is to minimize the interference caused by noise, thereby preserving the motor's ability to maintain high-quality performance. The application of LQR and LQT controllers is tested to see how effectively they can suppress the negative effects of noise and enhance the motor's response to disturbances, ensuring it can still reach the target output with minimal deviation. The investigation into the impact of noise on DC motors is essential for improving the reliability and efficiency of these systems, especially in industrial environments where noise and disturbances are common. By implementing advanced control methods such as LQR and LQT, it is possible to optimize the motor's performance and achieve greater precision in its operation. The results of this study will contribute to the development of more robust control systems that can mitigate the impact of external disturbances, ensuring that DC motors continue to perform efficiently and accurately in real-world applications. Ultimately, this research provides valuable insights into the importance of noise management and the role of control strategies in enhancing the performance and reliability of DC motors.

Keywords: DC motor, noise, LQR, LQT, system optimization, control strategies.

1. Introduction

actuators, and their usage has expanded significantly with the advancement of technology. One of the notable advantages of DC motors is their ability to operate quietly and provide precise speed control, making them highly valued in industries where consistent performance is required. However, despite these benefits, there are still several challenges associated with DC motors, such as the issue of output torque not reaching the desired set point. A well-performing DC motor must be resilient to external disturbances or noise and exhibit a quick and accurate response to ensure optimal performance. The speed and accuracy of the motor are directly linked to the quality of the products being produced. If the motor's response is slow or its accuracy is poor, it can negatively impact the final product's quality and, in some cases, lead to product failure (Bai et al., 2020; Yulianto & Aji, 2022).

The motor's maximum speed is typically achieved when it operates without a load (Nugraha & Ravi, 2023). However, when the motor is under load, a voltage drop often occurs, leading to inconsistencies in the motor’s speed. To address this issue, speed control techniques are commonly applied to stabilize the speed of DC motors when carrying a load. In industrial applications, control systems with fast response times and high accuracy are essential to maintain the performance and efficiency of the motor. Among the available control systems, the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) are popular options

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for managing the motor's speed and response. The LQR controller is particularly favored for its simplicity and ease of implementation, requiring only the values for the Q and R matrices, which result in the feedback gain (K) and setpoint tracking (L) parameters (Prasetya & Zuhrie, 2019; Rizki et al., 2021).

In contrast, the Linear Quadratic Tracking (LQT) system is a more sophisticated control method that ensures the output follows a predetermined path based on the input. This tracking system is designed to provide more precise control, particularly in systems that require exact path following or setpoint tracking. The implementation of LQR and LQT controllers provides an effective solution to enhance the performance of DC motors, enabling them to maintain high-speed accuracy and minimize disturbances. These control methods are crucial for improving motor response and ensuring consistent and reliable operation in various industrial applications, where high performance is required to meet production demands (Akbar et al., 2016; Suhandi et al., 2021).

2. Material and methods

2.1. Material

A DC motor is an electromechanical device that transforms direct current (DC) electrical energy into mechanical energy, specifically into rotational motion. The working principle of a DC motor revolves around the interaction between two magnetic fields: one created by the field coil and the other by the armature winding. These magnetic fields generate forces that cause the armature to rotate, thus producing mechanical motion that can be used to drive various machines and devices (Nugraha et al., 2024).

The field coil in a DC motor is known as the stator, which remains stationary during operation, while the armature winding is called the rotor, which rotates as a result of the interaction between the magnetic fields. The armature is where the current is supplied, and it is the component that undergoes the motion that drives the motor's mechanical output. The rotation of the rotor generates torque that can be harnessed to perform various tasks in industrial applications, such as in conveyor belts, pumps, and fans (Satrianata et al., 2023; Nugraha & Arifuddin, n.d.).

The efficiency and performance of a DC motor are largely influenced by the interaction between the stator and rotor. Optimizing these interactions allows for better control of the motor's speed and torque output. In modern applications, DC motors are frequently used due to their ability to provide precise speed control and high torque at low speeds. These motors are also favored in systems where variable speed is essential, such as robotics and automation systems (Kurniawan et al., 2023; Dermawan et al., 2023).

Figure 1. motor DC C34-L70 (*Datasheet Permanent Magnet DC Motors C23, 34, 42 Series)*

Winding Code	10		*Back EMF*	5.76	*volts/KRPM*
L = Length	7.00	*inches*		0.06	*volts/rad/sec*
	177.80	*millimeters*	*Terminal Resistance*	0.14	*ohms*
Peak Torque	855.0	*oz-in*	*Terminal Inductance*	0.24	*mH*
	6.038	*Nm*	*Motor Constant*	20.82	*oz-in/watt*$^{1/2}$
Continuous Stall Torque	95.0	*oz-in*		0.15	*Nm/watt*
	0.671	*Nm*	*Rotor Inertia*	0.042	*oz-in-sec*^{2}
Rated Terminal Voltage	12 - 30	*volts DC*		2965.83	*g-cm*^{2}

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Terminal Voltage	24	*volts DC*	*Friction Torque*	17	*oz-in*
Rated Speed	4450	*RPM*		0.12	*Nm*
Rated Speed	466.00	*rad/sec*	*Thermal Resistance*	3.70	*°C/watt*
Rated Torque	75.0	*oz-in*	*Damping Factor*	3.00	*oz-in/KRPM*
	0.53	*Nm*		0.02	*Nm/KRPM*
Rated Current	13.00	*Amps*	*Weight*	128.00	*oz*
Rated Power	247.0	*Watts*		3628.74	*g*
	0.33	*Horsepower*	*Electrical Time Constant*	1.7143	*millisecond*
Torque Senstivity	7.79	*oz-in/amp*	*Mech. Time Constant*	13.72031	*millisecond*
	0.06	*Nm/amp*	*Speed/Torque Gradient*	-3.120097	*rpm/oz-in*

Table 1. Spesification C34-L170

2.1.1. Software Mathlab

MATLAB (Matrix Laboratory) is a powerful software application used for numerical analysis, mathematical computations, and advanced programming. It is designed based on the principles of matrix operations, allowing users to perform a wide range of mathematical tasks, including matrix manipulation, data visualization, and algorithm development. MATLAB provides an interactive environment where users can write scripts and functions to solve complex problems, perform simulations, and analyze data. In this research, the version of MATLAB utilized is R2018b, which offers various tools and features for processing numerical data and conducting detailed computational analysis efficiently. This version includes enhanced functionalities and improved performance for handling large datasets and executing mathematical operations.

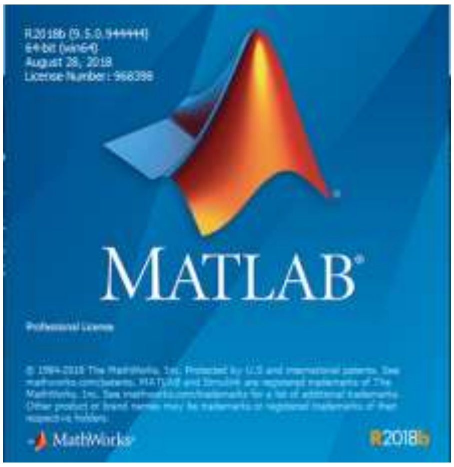

Figure 2. Software Mathlab (pinterest)

2.2. Literature Study

A DC motor is a type of electric motor that uses direct current to convert electrical energy into motion or mechanical energy. In many cases, the full potential of the DC motor is not fully realized. Therefore, system optimization is needed to maximize the motor's potential. However, in this experiment, the system optimization stage for the DC motor has not yet been reached. System optimization itself is a set of mathematical techniques that involve defining and analyzing a problem-solving program to achieve better results than before.

2.2.1. *Linear Quadratic Regulator* (LQR)

Linear Quadratic Regulator (LQR) is a state-space-based control method used to determine the input signal that drives a linear system from its initial state to a desired condition, minimizing a quadratic performance index. The advantage of LQR lies in its ability to provide an optimal solution for control system problems that use a state-space framework. LQR

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involves two key parameters: the matrices Q and R. LQR is applied to a DC motor circuit within the Simulink software on MATLAB.

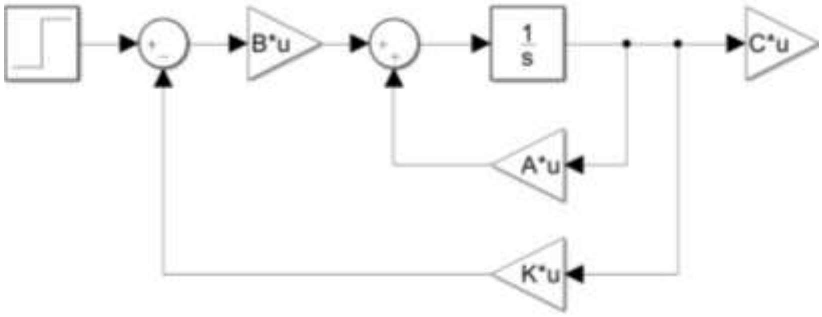

Figure 3. block diagram LQR

Simulink in MATLAB can be used to design circuits with an LQR control system. The scope component in Simulink displays the diagram of the circuit's output. From this, the stability of the system's performance for the LQR-controlled circuit can be observed.

2.2.2. ***Linear Quadratic Tracking* (LQT)**

Linear Quadratic Tracking (LQT) is an optimal control system developed for linear plants to address tracking issues. The goal of LQT is to adjust the output so that it matches the desired target.

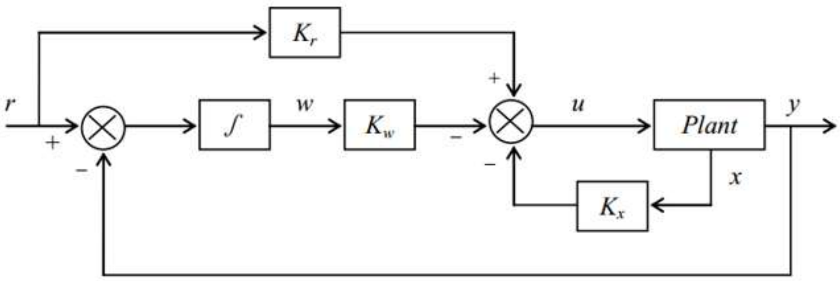

Figure 4. block diagram LQT

Simulink in MATLAB can be used to design circuits with an LQT system. The scope component in Simulink will display the output diagram, allowing the stability of the calculated results for the circuit to be observed.

2.2.3. System Formula

The following is a state space model of the LQR system.

$$dx/dt = Ax + Bu \quad (1)$$

$$y = Cx + Du \quad (2)$$

y is the output you want to control. The goal of LQR is to regulate/make output y zero with as little input as possible.

$$A = \begin{bmatrix} -\frac{R}{L} & -\frac{K}{L} \\ \frac{K}{J} & -\frac{b}{J} \end{bmatrix} \quad (3)$$

$$B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \quad (4)$$

$$C = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (5)$$

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$$Q = \begin{bmatrix} 0.00000001 & 0 \\ 0 & 0.000000001 \end{bmatrix} \quad (6)$$

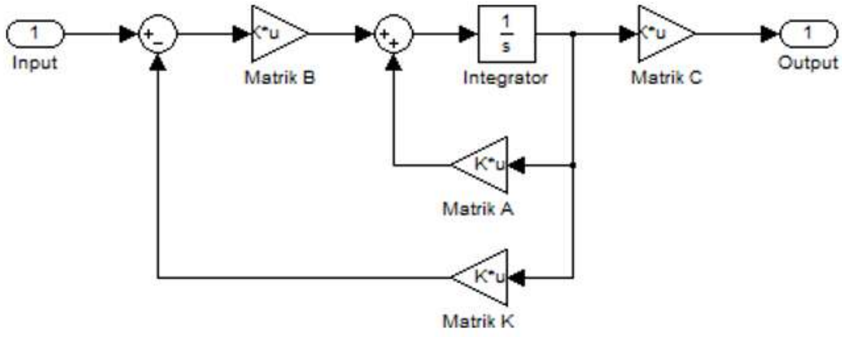
The system equation and LQT output are as follows:

$\dot{x} = Ax + Bu$ (7)

$y = Cx$ (8)

The regulator and tracking problem can be solved with the Riccati equation as follows:

$A^TP + PA - PBR^{-1}B^TP + Q = 0$ (9)



Gambar 5. Optimal Control Block Diagram
Image source: Matlab Simulink

The following is the Riccati equation in the form of a matrix with small values:

$K = R^{-1}B^TP$ (10)

$u = -Kx$ (11)

2.3. Network Creation

The circuit created at this stage in the Simulink software is a circuit for LQR and LQT. In creating a circuit, programming in Matlab must be done. The following is the programming used for the circuit:

- LQR

```
close all; clc; clear;
%LQR
J = 0.042   %momen inersia
b = 0.02    %damping ratio
K = 0.06    %konstanta torsi (Kt)
R = 0.14    %resistansi
L = 0.24    %induktansi
%state space
A = [-R/L -K/L; K/J -b/J]
B = [1/L; 0]
C = [1 0]
D = 0
Q = [0.00000001 0; 0 0.000000001];
R = 1;
[K,S,e] = lqr(A,B,Q,R);
Ac = A - B*K;
step (Ac,B,C,D,1)
```

- LQT

```
close all; clc; clear;
%LQT
J = 0.042   %momen inersia
b = 0.02    %damping ratio
K = 0.06    %konstanta torsi (Kt)
```

```
R = 0.14     %resistansi
L = 0.24     %induktansi
%state space
A = [-R/L -K/L; K/J -b/J]
B = [1/L; 0]
C = [1 0]
D = 0
Q = [1 0; 0 1];
R = 1;
[S, eig, G] = care(A,B,Q);
Kx=inv(R)*B'*S
Kr=(Kx*(inv(A))*B-eye(1))*(inv(C*(inv(A))*B))
Ahat=[-R/L -K/L 0;K/J -b/J 0; 1 0 0]
Bhat=[1/L; 0;0]
Qhat=[1 0 0;0 1 0;0 0 1];
Rhat=6;
[Shat,eighat,Ghat] = care(Ahat,Bhat,Qhat)
Khat=inv(Rhat)*Bhat'*Shat
Kw=Khat(:,3)
```

The following are the series that have been created:

2.3.1. Letwork LQR

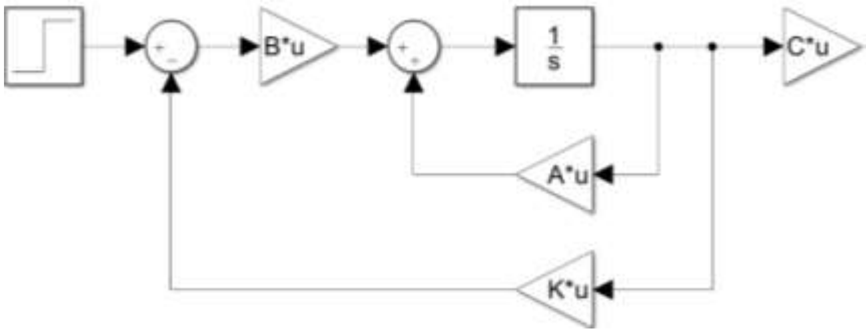


Figure 6. network LQR

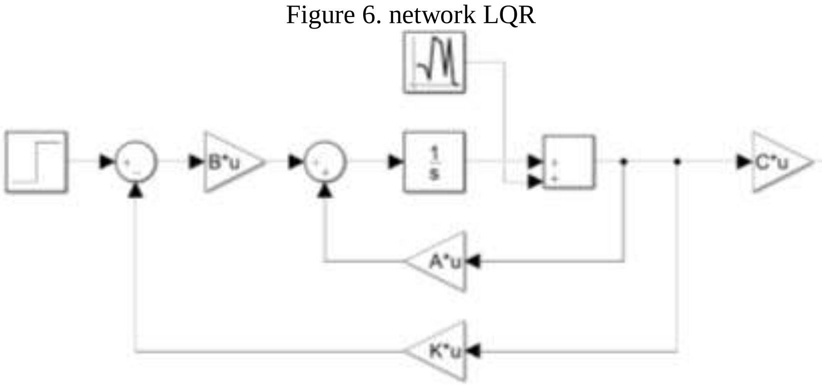


Figure 7. network LQRwith noise

2.3.2. Network LQT

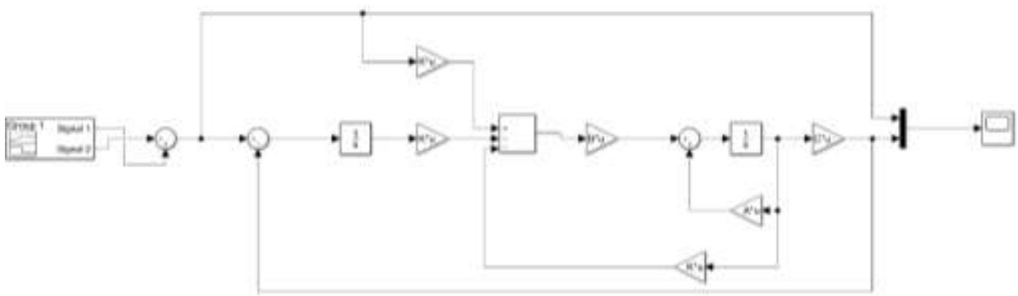


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Figure 8. network LQT

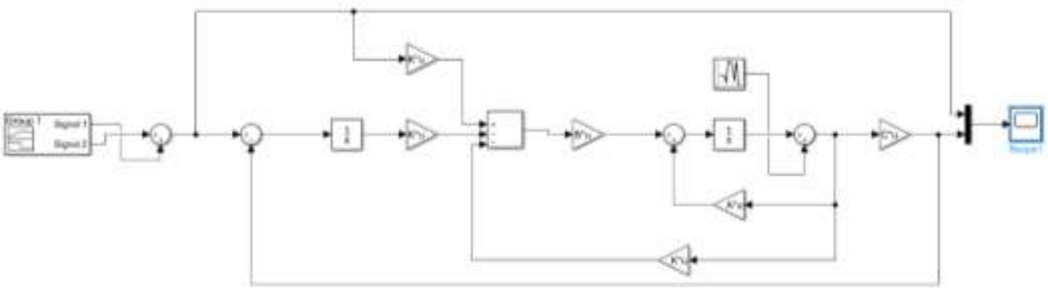

figure 9. Network LQT with Noise

2.4. Methods

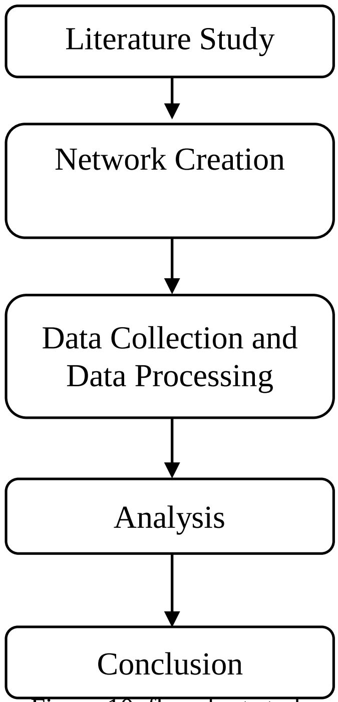

Figure 10. flowchart study

- Literature Study
  In this phase, a literature review is conducted to understand the research object and the methods used for data collection.
- Circuit Creation
  The next step involves creating a circuit in Simulink based on the required circuit type. The circuit is then run to analyze and collect data.
- Data Collection and Processing
  In this phase, the necessary data is gathered. Then, the data is processed for analysis.
- Analysis
  Analysis is performed in this phase on the results obtained from the experiment. The discussion focuses on the steps of data calculation.
- Conclusion
  In this phase, the results of the experiment are concluded based on the processed data. The conclusion is drawn from the calculations made earlier.

3. Results and discussion

3.1. Grafik Diagram LQR

3.1.1. LQR without Nois

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Figure 11. grafik diagram without noise

From the graph of the LQR circuit without noise above, it can be seen that the spike in system output reaches a figure of around 4.1 in the 2nd second and takes around 7 seconds to stabilize. In this way, it can be seen that the spike that occurred was too large and required optimization of the system.

3.1.2. LQR with Noise

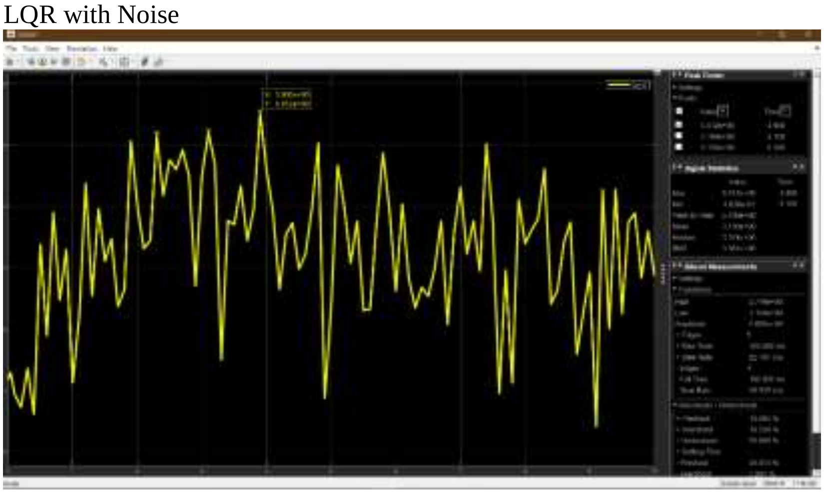

Figure 12. grafik diagram LQT with noise

In the LQR circuit that is given noise, the output experiences ripple with a peak of 3.9 in 4 seconds. The installed noise has an effect that greatly affects the quality of motorbike performance. This can be seen from the form of the output signal which looks quite messy.

3.2. Grafik diagram LQT

3.2.1. LQT without noise

Figure 13. grafik diagram LQT withoit noise

In the LQT output graph without noise, you can see the pulse signal formed by the input. The highest point on the first input is 4.2 in 4 seconds. This indicates a high surge and needs to be reduced further to optimize the motor's potential.

3.2.2. LQT with noise

Figure 14. grafik diagram with noise

The graph above shows that the added noise affects the output of the input. The noise provided makes the output signal too messy so treatment is needed to minimize ripple.

4. Conclusion

Based on the simulation design that has been created and successfully run, it can be concluded that noise has a significant impact on the output of a system, especially in control systems used for motor speed regulation. The presence of noise, whether introduced externally or generated within the system itself, can lead to various disturbances that interfere with the desired outcome. In this study, the introduction of noise in the form of random fluctuations and disturbances has caused the output to degrade significantly, which reduces the overall quality of the system's performance. The system's output, in this case, becomes more unstable, making it difficult to achieve the desired target values or setpoints. This outcome highlights the importance of mitigating noise effects in system design and control strategies.

The implementation of the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods was intended to ensure that the output of the system meets the expectations and follows the desired trajectory. Both of these methods are well-established in control theory for their ability to optimize the response of dynamic systems. However, despite the advantages of these methods in stabilizing and improving system performance, the results from the experiment still showed signs of instability. This suggests that while the LQR and LQT methods can improve the system's performance, they are not entirely immune to the disruptive effects of noise. The instability observed in the measurement results could be attributed to several factors, including the incorrect selection of variables within the motorbike specifications used in the simulation model. The parameters chosen for the motor's specifications might not be accurate enough to reflect the actual dynamics of the system, leading to suboptimal control performance.

This issue underscores the need for more precise modeling and parameter selection in future experiments. Accurate formulas and more realistic variables are essential to fully unlock the potential of the motorbike system and achieve optimal performance. It is crucial to ensure that the specifications used in simulations closely match the real-world characteristics of the system being modeled. Therefore, further research should focus on refining the choice of variables and exploring advanced methods for noise filtering or compensation. More accurate formulas for system modeling, along with enhanced control strategies, could help minimize the influence of noise and lead to more stable and predictable outputs.

Additionally, future investigations should also consider testing the system in real-world conditions to evaluate the actual impact of noise on performance. While simulations offer valuable insights, real-world experiments often reveal complexities that simulations cannot fully capture. By comparing simulated results with practical outcomes, researchers can gain a deeper understanding of the noise-related challenges and develop more robust control systems. In summary, although the LQR and LQT methods show promise in improving system performance, further research with better parameter selection and noise mitigation techniques is necessary to demonstrate the true potential of the motorbike system.

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