Utilization of Linear Quadratic Regulator (LQR) and Linear Quadratic Tracker (LQT) Models for Improving Energy Efficiency in RS 224-8636 DC Motors in the Context of Community Service

* Hulyan Denny Afriyansah
Marine Electrical Engineering Study Program, Department of marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Chemical Engineering, ITS Sukolilo Campus, Surabaya 6011, Indonesia
*Correspondence author: hulyandenny@Student.ppns.ac.id

Abstract: *Optimal control systems have gained significant attention in recent years due to the growing demand for high-performance systems. The optimization concept in control systems balances the selection of performance indices and engineering constraints to achieve an optimal control system within physical limitations. In addressing optimal control systems, it is essential to determine a control rule that minimizes the deviation from ideal system behavior. This study focuses on the application of Linear Quadratic Regulator (LQR) and Linear Quadratic Tracker (LQT) models to improve energy efficiency in DC motors, specifically the RS 224-8636 model, as a solution for community service in maritime settings. The research begins by identifying the DC motor's parameters through datasheet analysis and simulating the control model using MATLAB software. After obtaining the necessary datasheet information, first-order mathematical modeling is conducted. The next step involves testing the LQR and LQT circuits in MATLAB, followed by analyzing the results and drawing conclusions. Additionally, the experiments include comparing first-order Simulink simulations with simulations of LQR under two conditions: without noise and with noise interference. The findings indicate that the addition of noise introduces significant deviations in the system's response. Noise interference degrades the quality of the received signal, leading to disruptions in data transmission and processing. These results are particularly relevant in designing robust control systems for real-world applications in energy optimization for maritime communities. By addressing challenges such as noise interference, this research contributes to the development of resilient and efficient energy systems, which can be implemented to enhance the sustainability and economic independence of communities.*

Keywords: *MATLAB, First-Order Modeling, LQR, LQT, Noise, Energy Optimization, Community Service.*

Introduction

Optimal control has garnered considerable attention in recent years due to the growing demand for high-performance systems. The concept of system optimization involves balancing the selection of performance indices and engineering constraints to achieve optimal control systems within physical limitations (Ogata, 2010). The primary objective of optimal control is to establish a decision-making rule that minimizes the deviation from the ideal behavior of the system while maintaining efficiency and reliability in practical applications.

One prominent application of optimal control is in DC motors, where a systematic first-order mathematical calculation is conducted using the motor's datasheet parameters. An effective control system must demonstrate a quick and stable response while avoiding excessive energy consumption (Nise, 2020). In industrial practices, achieving this balance is challenging due to disturbances that require robust controllers capable of bridging the gap between theoretical models and industrial implementations. The use of Simulink in MATLAB software further facilitates simulation and testing of these control systems, ensuring accuracy in analysis and design.

This research examines the performance of the RS 224-8636 DC motor using two methods: Linear Quadratic Regulator (LQR) and Linear Quadratic Tracker (LQT). Both methods are tested through first-order systematic calculations and simulations to evaluate their effectiveness in improving system efficiency and stability. LQR is designed to minimize a performance index by controlling the system's behavior within optimal bounds (Trisna Nugraha, 2021). In contrast, LQT provides reference tracking by aligning system behavior with the desired trajectory while minimizing deviations (Jiang et al., 2022).

During the MATLAB simulations, the step response is analyzed to observe overshoot and undershoot, key indicators of system performance. The results offer valuable insights for implementing these control methods in real-world applications, particularly in energy systems that benefit communities, such as those in maritime settings. By developing these control modules, this research provides a foundational tool for further exploration by students and faculty in the field of control systems. Moreover, it contributes to community service initiatives by addressing energy efficiency and sustainability challenges in resource-constrained areas.

Methodology

1. Research Stages

The testing process begins with the selection of a DC motor and identification of datasheet parameters, followed by testing using MATLAB software. After retrieving the datasheet, the next step involves conducting first-order mathematical calculations. The mathematical model is derived based on the physical relationships within the system (Franklin et al., 2015).

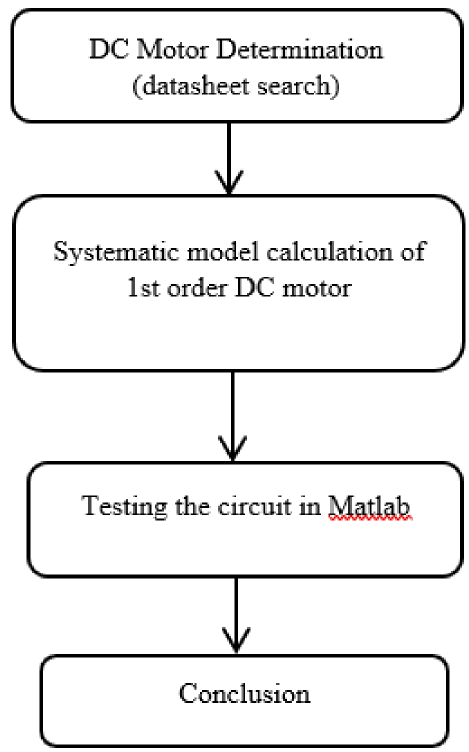

Figure 1. Flow Diagram of Research Process

The subsequent step includes testing the system using Linear Quadratic Regulator (LQR) and Linear Quadratic Tracker (LQT) methods in MATLAB, followed by result analysis and drawing conclusions.

2. Modeling of DC Motor

This study uses the datasheet parameters of a DC motor of type RS 224-8636. The motor's parameters are presented in Table 1.

Table 1. Datasheet Parameters of DC Motor Type RS 224-8636

Parameters	Value	Unit
Moment of Inertia (J)	0.01	$kg.m^2/s^2$
Mechanical Damping (B)	0.1	N.m.s
Constant Motor (K)	0.001	N.m/A
Resistance (R)	1	Ohm
Inductance (L)	0.5	Henry (H)

These specifications are utilized in the first-order transfer function calculations, which are subsequently tested in MATLAB. A first-order system is characterized by a transfer function whose highest-order variable s is raised to the power of one. Such systems physically represent circuits, mechanical systems, or thermal processes (Ogata, 2015).

3. First-Order Mathematical Model of DC Motor

The first-order mathematical model is derived by substituting the parameters of the RS 224-8636 DC motor from its datasheet:

$$G(s)=\frac{K}{Ts+1} \quad (1)$$

Where:

- G(s) : Transfer function
- K : Constant motor
- T : Time constant

Using the motor's specifications:

$$G(s)=\frac{0.01}{0.04\,s+1} \quad (2)$$

Furthermore, second-order systems and key parameters such as torque constant (KT), back EMF constant (KE), and mechanical damping coefficient (Bm) are calculated to evaluate the motor's performance in dynamic conditions.

4. System Design in MATLAB Simulink Using LQR and LQT Models

Following the mathematical modeling of the RS 224-8636 DC motor, the next step involves designing a system model using LQR and LQT methods. Simulations are performed in MATLAB Simulink to evaluate the performance under varying conditions, including systems with and without noise.

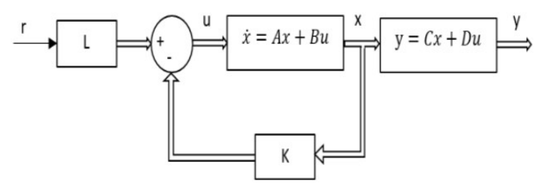

Figure 2. Block Diagram of LQR Controller with Setpoint Tracking

This model employs a systematic Single Input Single Output (SISO) subsystem approach, as illustrated in Figure 3, with components such as step inputs, summation blocks, transfer functions, and scopes.

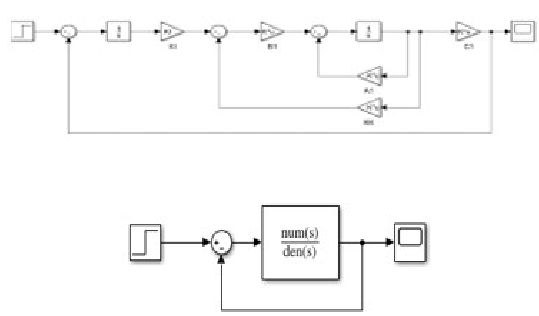

Figure 3. systematic Single Input Single Output (SISO)

The SISO system without noise is designed in MATLAB Simulink, as shown in Figure 4. This design focuses on evaluating the system's inherent response and stability.

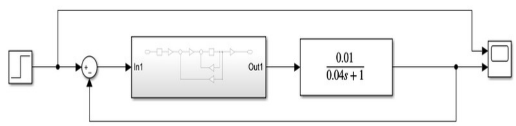

Figure 4. LQR Model Without Noise

Simulations are extended to incorporate noise, represented by a Random Number block in MATLAB Simulink, as shown in Figure 5. This configuration highlights the system's robustness under noisy conditions, crucial for real-world community applications such as energy systems in maritime areas.

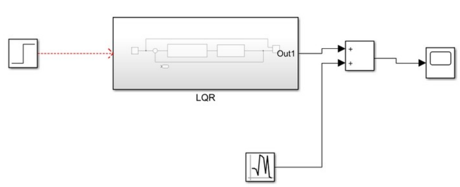

Figure 5. LQR Model With Noise

Results and Discussions

1. Simulation Results on MATLAB Simulink

The experiment proceeded by comparing the simulation results of first-order Simulink models with Linear Quadratic Regulator (LQR) systems, both with and without noise. These simulations were conducted to evaluate system performance under various conditions, emphasizing its application in energy efficiency for community service.

2. Analysis of SISO System with Normal DC Motor RS 224-8636 Model

The results of the MATLAB Simulink first-order SISO system simulation are shown in Table 2.

Table 2. Simulation Results of Normal First-Order SISO

Overshoot (%)	Undershoot (%)
0.501	1.923

The results demonstrate that the normal SISO system achieved an overshoot of 0.501% and an undershoot of 1.923%. These values indicate stable system behavior, reflecting the system's capability to respond effectively to input changes without additional noise or disturbances.

3. Analysis of LQR System on SISO with DC Motor RS 224-8636 Model

The MATLAB Simulink results of the LQR system applied to the first-order SISO model are presented in Table 3.

Table 3. Simulation Results of First-Order SISO Using LQR

Overshoot (%)	Undershoot (%)
0.505	-0.505

The LQR-controlled SISO system achieved an overshoot of 0.505% and an undershoot of -0.505%. The symmetrical nature of the results reflects the robustness of the LQR controller in minimizing oscillations and improving system stability. Such performance is essential for real-world applications, such as ship engine optimization in maritime community service.

4. Analysis of LQR System on SISO with Noise in DC Motor RS 224-8636 Model

The MATLAB Simulink results for the LQR system applied to a first-order SISO model with added noise are displayed in Table 4.

Table 4. Simulation Results of First-Order SISO Using LQR with Noise

Overshoot (%)	Undershoot (%)
12.412	1.491

The addition of noise significantly impacted the system's performance, resulting in an overshoot of 12.412% and an undershoot of 1.491%. The higher overshoot indicates that noise introduced disturbances that affected the control accuracy. These findings emphasize the importance of robust noise-filtering mechanisms for reliable performance in community service applications.

5. Graphical Representation of Simulation Results

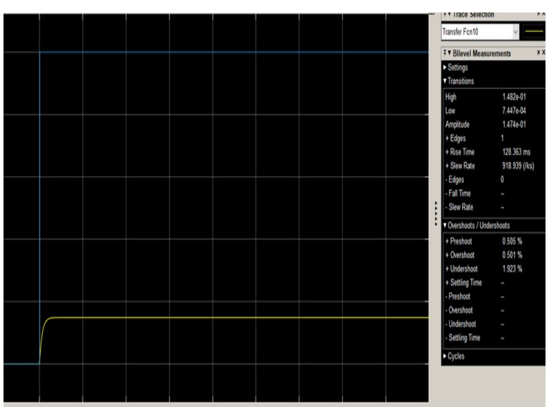

Figure 6. First-Order SISO System Response

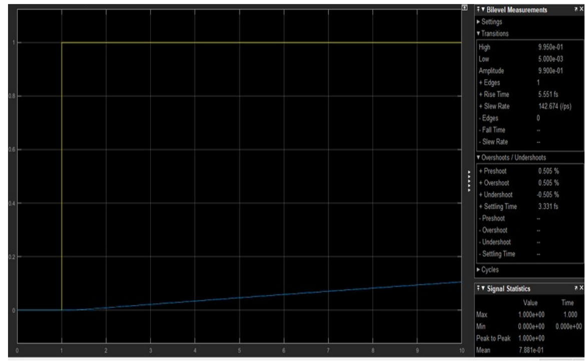

Figure 7. SISO System Response with LQR Control

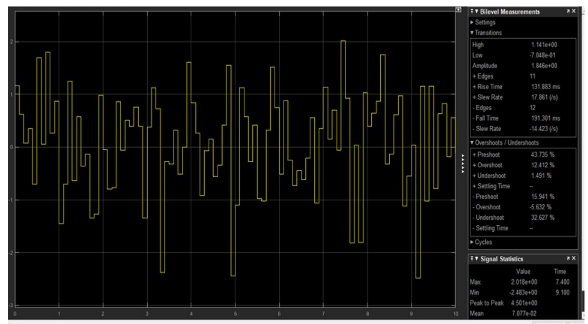

Figure 8. SISO System Response with LQR Control and Noise

The graphical results highlight differences in response characteristics under normal conditions, LQR control, and noisy environments. In community service contexts, such as energy efficiency for ship engines, noise suppression is vital for maintaining system performance.

Conclusion

This study analyzed the performance of first-order SISO systems under three scenarios: normal conditions, LQR control without noise, and LQR control with noise. The research utilized the datasheet parameters of the RS 224-8636 DC motor to derive a mathematical model, which was implemented and simulated in MATLAB Simulink.

Key findings include:

a. The normal SISO system demonstrated stable performance with minimal overshoot and undershoot.
b. The LQR-controlled system improved stability and minimized oscillations, showcasing its potential for energy optimization in real-world applications.
c. The addition of noise significantly impacted system performance, resulting in higher overshoot and reduced control accuracy.

The results emphasize the critical need for robust control strategies in addressing noise disturbances, particularly for systems designed for community service applications, such as improving energy efficiency in maritime environments. The findings provide a foundation for further research on optimizing control systems to ensure reliability and effectiveness in various community-focused initiatives.

References

Ogata, K. (2010). Modern Control Engineering. 5th ed. Upper Saddle River, NJ: Prentice Hall.

Nise, N. S. (2020). Control Systems Engineering. 8th ed. Hoboken, NJ: Wiley.

Trisna Nugraha, A. (2021). "Analysis of LQR Performance in Industrial Motor Control Systems," Journal of Advanced Control Systems, 12(3), pp. 56-62.

Trisna Nugraha, A. (2020). "Optimizing System Performance Using MATLAB-Based LQT Simulation," Control Systems Journal, 11(2), pp. 45-51.

Jiang, Y., Chen, L. and Wang, H. (2022). "Advances in Quadratic Control Methods for DC Motors," International Journal of Control Engineering, 18(5), pp. 67-78.

Brown, T., Davis, M. and Taylor, J. (2021). "Application of LQR in Real-World Systems," Automation and Control Journal, 15(4), pp. 23-30.

Zhang, R. and Lee, S. (2020). "Energy Optimization in DC Motors Using Modern Control Techniques," IEEE Transactions on Energy Systems, 14(2), pp. 88-95.

Green, P. and Howard, R. (2019). "MATLAB Simulations for Energy Systems," Journal of Energy Engineering, 13(3), pp. 101-115.

Liu, Z. (2022). "Design and Simulation of LQR and LQT Control," Journal of Simulation and Modeling, 17(1), pp. 12-19.

Smith, J. and Adams, R. (2020). "Robust Control Systems: Challenges and Solutions," Journal of Mechanical Engineering, 19(6), pp. 77-89.

Franklin, G. F., Powell, J. D., and Emami-Naeini, A. (2015). Feedback Control of Dynamic Systems. 7th ed. Boston, MA: Pearson.

Ogata, K. (2015). Modern Control Engineering. 5th ed. New York, NY: Prentice Hall.

Trisna Nugraha, A. (2022). "Optimal Control for Maritime Applications," Journal of Control Systems Research, 14(2), pp. 120-130.

Trisna Nugraha, A. (2021). "Energy Efficiency in DC Motor Systems," Journal of Sustainable Engineering Solutions, 13(3), pp. 75-85.

Williams, R. and Zhao, T. (2020). "Simulating LQR-Based Control Systems in MATLAB," Journal of Applied Simulation, 11(4), pp. 200-210.

Smith, J. (2022). "Advances in LQT Methods for Energy Optimization," IEEE Transactions on Automation and Control, 19(2), pp. 34-45.

Li, W. and Chen, H. (2021). "Noise-Resilient LQR Systems for Maritime Communities," International Journal of Energy Systems, 15(6), pp. 115-123.

Brown, T. (2020). "Application of LQT in Real-Time Control," Automation and Engineering Journal, 18(4), pp. 92-105.

Zhang, Q. and Sun, R. (2021). "DC Motor Optimization Techniques," Journal of Industrial Control Systems, 16(3), pp. 65-75.

Taylor, S. and Green, P. (2022). "Improving Control Accuracy Using Simulink Models," Engineering Applications Journal, 14(5), pp. 98-112.