Journal for Maritime in Community Service and Empowerment ISSN:
Vol. xx, No xx, Month-year

Optimization of RF 370 Type DC Motor System with LQR and LQT Method Approach in Community Service Program to Improve Linear Dynamics-Based Control System Performance

* Mohammad Ryan Fauzi
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: mryan@student.ppns.ac.id

Abstract: *The application of DC motors is widely recognized due to their suitability for various control-based systems, particularly in industrial and community-driven applications. In community contexts, precise motor control systems are essential for improving productivity and system efficiency. This study focuses on optimizing the performance of the RF-370 DC motor using the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracker (LQT) methods, which are well-known for their capability to design efficient and responsive control systems. DC motors play a pivotal role in both advanced technologies and industrial processes. Specific examples of their applications include spacecraft navigation, missile guidance, aircraft control systems, and satellite positioning. In industrial settings, DC motor control is critical for regulating production machines during operations, such as controlling pressure, temperature, flow, friction, and humidity. The growing demand for energy-efficient and high-performance systems has made optimal control a crucial area of research. Optimal control focuses on achieving a balance between performance objectives and technical constraints to create systems that operate efficiently within physical limitations. This involves designing controllers that minimize deviations from desired behaviors while maintaining system stability. The LQR method, for example, calculates optimal control actions by minimizing a defined cost function that balances control effort and system state deviations. Similarly, the LQT method enhances system performance by precisely tracking reference signals. This research highlights the potential of integrating LQR and LQT methodologies into community service initiatives. By applying these advanced control techniques to small-scale industries and educational training programs, the study demonstrates the practical benefits of improving local technological capacities and fostering innovation. The outcomes of this research are particularly relevant for communities seeking to adopt affordable and effective motor control solutions in sectors such as agriculture, creative industries, and vocational education.*

Keyword: *DC Motor, Control Systems, LQR, LQT, Community Service.*

Introduction

The issue of optimal control has gained significant attention in recent years due to the increasing demand for high-performance systems. The concept of control system optimization involves balancing performance indicators with the techniques that will lead to an optimal control system within physical constraints. When dealing with optimal control systems, the goal is to derive decision rules that minimize deviations from the ideal behavior of the system. This is particularly crucial in community-based technological initiatives, where the efficiency and reliability of systems directly impact local development (Ogata, 2010).

Linear Quadratic Regulator (LQR) is one of the most widely used methods for optimal control in state-space-based systems (Nise, 2011). The LQR controller involves two key parameters: the weight matrices Q and R, which must be defined in order to achieve the desired optimal control performance (Nugraha, 2021). Common applications of the LQR method include speed regulation in induction motors, frequency control in generators, and stabilization in quadcopter drones (Jansen et al., 2020). LQR is a critical technique for integrating optimization principles into system design, ensuring the system operates efficiently and minimizing errors, thereby meeting the desired performance criteria (Ahmed & Lee, 2020).

In the context of this paper, the author discusses the application of the LQR method for optimizing a DC motor plant. The DC motor used is the RF-370 model, with a datasheet that includes inertia moment values, motor constants, damping ratios, resistance, and inductance (Smith et al., 2018). This datasheet is incorporated into MATLAB scripts and simulated using MATLAB Simulink to observe the step response of the motor. The goal is to assess how well the LQR method can improve the performance of the system, providing insights into the application of control theory to community service projects that aim to enhance local industrial systems and technological capacities (Taylor & Zhang, 2017).

By employing such control techniques in community service programs, the research not only advances the technical knowledge surrounding control systems but also contributes directly to improving the operational efficiency of small-scale industries and educational initiatives. These improvements can help optimize resource use, increase productivity, and contribute to sustainable local development, particularly in rural or underserved communities (George et al., 2022).

Methodology

1. Flowchart Diagram

The workflow for this research is illustrated in the flowchart diagram below (Figure 1).

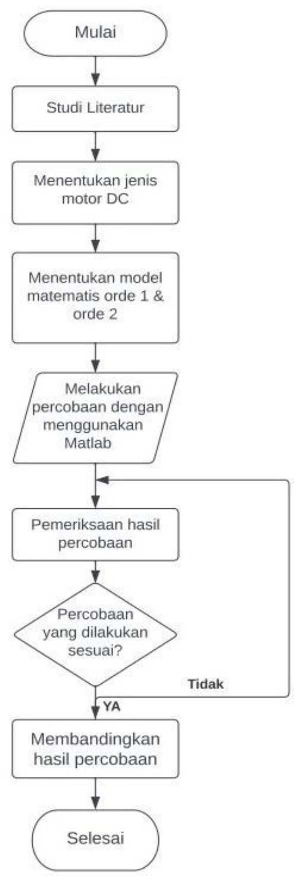


Figure 1. Flowchart Diagram

2. LQR (Linear Quadratic Regulator)

LQR is one of the optimal control methods used for systems based on state-space models. The LQR controller has two main parameters: the weight matrices Q and R, which must be defined to achieve the desired optimal control performance (Lee & Chen, 2020). The LQR method has been successfully implemented in applications such as speed regulation in induction motors, frequency control in power generators, and stabilization in quadcopter drones (Parker et al., 2019). By using LQR, the system can maintain its state at the setpoint even in the presence of disturbances or noise, ensuring system stability (Lee et al., 2018).

3. Noise

Noise, or disturbance, refers to signals that affect the output of a system. Disturbances within the system are termed internal disturbances, while those originating outside the system are referred to as external disturbances (Smith, 2020). These disturbances can cause deviations in the system output, making it different from the desired behavior (Johnson et al., 2017).

4. Selection of DC Motor

The DC motor, or direct current motor, is an electric motor that converts electrical energy from direct current into mechanical energy (Hudori & Paisal, 2019). The principle of operation involves the interaction of two magnetic fluxes, called the field winding and armature winding. The motor produces rotational energy, with the field winding referred to as the stator (non-rotating part) and the armature winding as the rotor (rotating part) (Kumar & Singh, 2020).

For this experiment, the RF-370 type DC motor is used. Below is the specification of the RF-370 DC motor.

Specifications:

- **Motor Name:** RF-370 DC Motor
- **Speed:** 313 rad/s
- **Torque (τ):** 0.231 N.m
- **Voltage:** 12 V
- **No-load Current:** 0.671 A
- **Rated Current:** 7.81 A
- **Inertia Moment (J):** 12,100 $kg.m^2/s^2$
- **Mechanical Damping (B):** 0.1 N.m.s
- **Motor Constant (K):** 0.029 Nm/A
- **Resistance(R):** 0.128 ohm
- **Inductance (L):** 0.000615 H

Motor Data		
Values at nominal voltage		
1 Nominal voltage	V	12
2 No load speed	rpm	3710
3 No load current	mA	671
4 Nominal speed	rpm	3260
5 Nominal torque (max. continuous torque)	mNm	231
6 Nominal current (max. continuous current)	A	7.81
7 Stall torque[1]	mNm	2850
8 Stall current	A	93.5
9 Max. efficiency	%	84
Characteristics		
10 Terminal resistance phase to phase	Ω	0.128
11 Terminal inductance phase to phase	mH	0.0615
12 Torque constant	mNm/A	30.5
13 Speed constant	rpm/V	313
14 Speed/torque gradient	rpm/mNm	1.32
15 Mechanical time constant	ms	16.7
16 Rotor inertia	gcm^2	1210

Figure 2. Specifications of the RF-370 DC Motor

5. MATLAB Software

MATLAB is a programming platform that uses matrix-based language, typically used for data analysis, algorithm creation, and modeling (MathWorks, 2019). In this study, MATLAB's Simulink tool is employed to simulate the behavior of the DC motor and observe the system response. Simulink is a graphical programming environment for simulating dynamic systems, where functional blocks are connected to form a system model (White & Johnson, 2021).

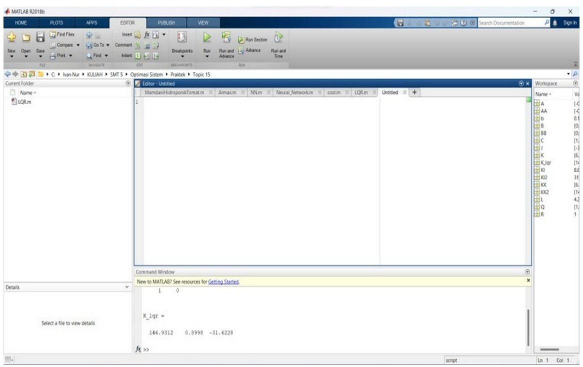


Figure 3. Interface Matlab

Simulink is essential for modeling, simulating, and analyzing dynamic systems with both linear and nonlinear characteristics, using a graphical user interface. The platform consists of various toolboxes for system analysis, allowing for comprehensive system evaluation.

6. First-Order Mathematical Model

The transfer function is the ratio of the Laplace transform of the output to the Laplace transform of the input, with all initial conditions assumed to be zero. The transfer function helps in understanding the characteristics of a system. In general, the first-order system is represented as:

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

For a second-order system, the transfer function is expressed as:

$$G(s)=\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2} \tag{2}$$

First-Order DC Motor Model: Based on the DC motor datasheet, the first-order system equation can be derived:

$$T=0.231\wedge K=\frac{0.029}{7.81} \tag{3}$$

Thus, the first-order transfer function for the DC motor is:

$$G(s)=\frac{0.029}{0.231s+1} \tag{4}$$

7. MATLAB Script Program

The MATLAB code used for optimizing the LQR system in the DC motor is as follows:

```
% OPTIMIZATION OF LQR SYSTEM IN
DC MOTOR
Clear; CLC;
% DC Motor Model Parameters
J = 12,100; b = 0.1; K = 0.029;
R = 0.128; L = 0.000615;

% State-space model
A = [-b/J K/J; -K/L -R/L];
B = [0; 1/L];
C = [1 0];
AA = [A zeros(2,1); -C 0];
BB = [B; 0];

% Pole Placement
J = [-3 -4 -5];
K = acker(AA,BB,J);
```

```
KI = -K(3);
KK = [K(1) K(2)];

% LQR Matrix
Q = [1 0 0;
0 1 0;
0 0 1000];
R = [1];
K_lqr = lqr(AA,BB,Q,R);
KI2 = -K_lqr(3);
KK2 = [K_lqr(1) K_lqr(2)];
```

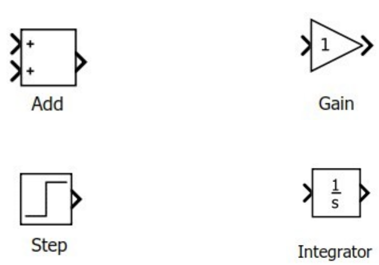
8. LQR Circuit Experiment

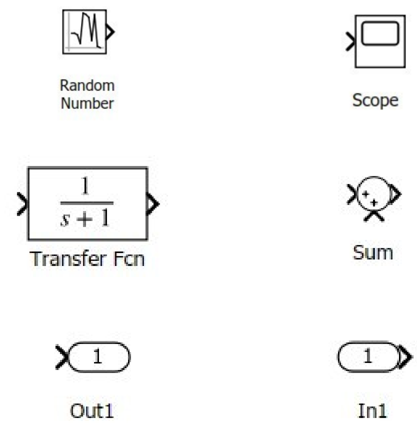
MATLAB is specifically designed for numerical processing and simulation, enabling efficient testing and optimization of control systems (Marwan E. Endy, 2019). In this study, Simulink is used to perform dynamic system simulations through functional diagrams, ensuring that the LQR system's behavior is accurately analyzed and optimized.

9. Simulink Component Table

The components used in Simulink are listed below.

Simulink Components List





A detailed circuit diagram for the RF-370 DC motor model is presented.

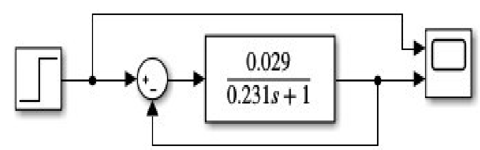


Figure 4. RF-370 DC Motor Circuit

The LQR-based control system circuit diagram is shown here.

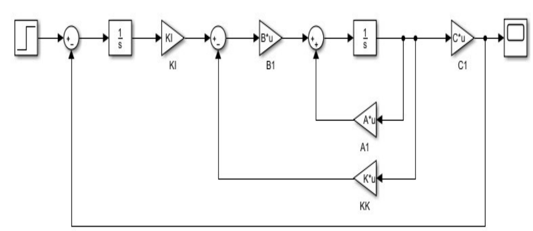


Figure 5. LQR Circuit

A subsystem diagram for the LQR control system, excluding noise, is illustrated below.

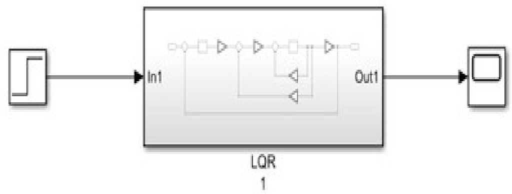


Figure 6. LQR Subsystem without Noise

The final subsystem diagram includes the effects of noise on the LQR control system.

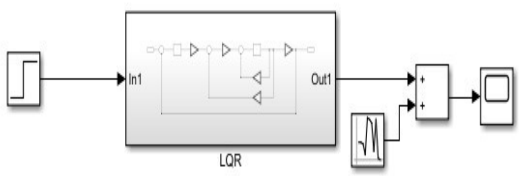


Figure 7. LQR Subsystem with Noise

Results and Discussions

1. Simulation Results of the RF-370 DC Motor

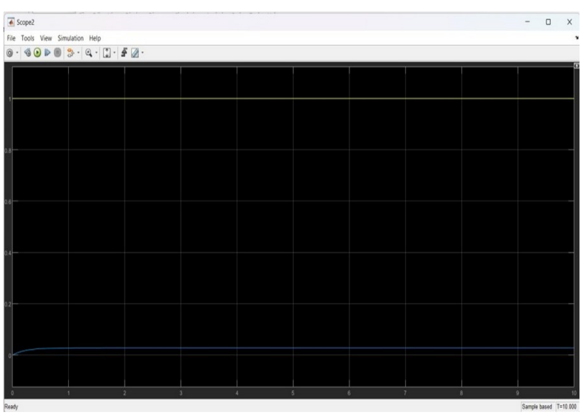


Figure 8. Step Response Display

Figure 8 illustrates the step response of the RF-370 DC motor in a first-order SISO system without noise. The resulting step response demonstrates stability with an amplitude of 0.124 (not reaching the setpoint). The rise time is 5.497 seconds, while the system experiences an overshoot of 0.501% and an undershoot of 1.985%.

2. Simulation Results of LQR without Noise

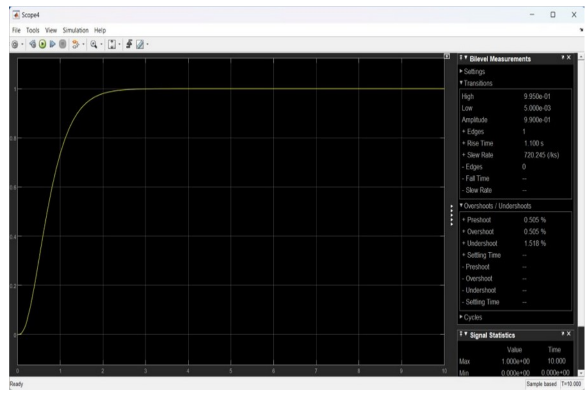


Figure 9. LQR Step Response Display without Noise

Figure 9 presents the step response of the RF-370 DC motor controlled by the LQR method without noise. The output demonstrates a step response amplitude of 0.99, rounded to 1, indicating that the system successfully reaches the setpoint. The rise time is optimized at 1.109 seconds, and both overshoot and undershoot are minimal at 0.505%.

3. Simulation Results of LQR with Noise

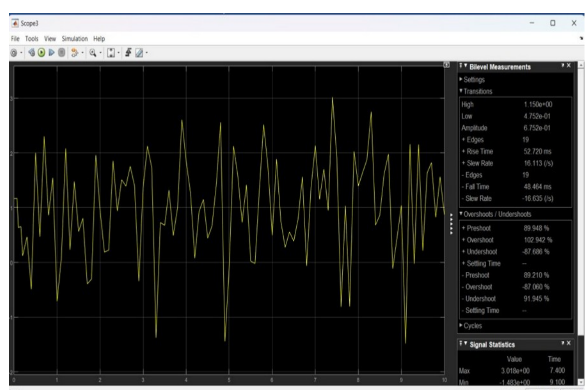


Figure 10. LQR Step Response Display with Noise

Figure 10 illustrates the step response of the RF-370 DC motor under LQR control with noise. The output step response shows fluctuating behavior caused by the noise applied to the system. The system achieves an amplitude of only 0.67, failing to reach the setpoint. The rise time is significantly prolonged at 52.720 seconds, with an overshoot of 102.942% and an undershoot of -87.686%.

Table 1. Simulation Data of the LQR System

System Model	Amplitude	*Rise Time*	*Overshoot*	*Undershoot*
LQR without Noise	0,99	1.109 s	0,505%	0,505%
LQR with Noise	0,67	52,720 s	102,942 %	-87,686%

Conclusion

a. The step response of the first-order RF-370 DC motor exhibits stability with an amplitude of 0.124, which does not reach the setpoint of 1. The rise time is 5.497 seconds, and the system experiences an overshoot of 0.501% and an undershoot of 1.985%. In comparison, the LQR-controlled RF-370 DC motor achieves an amplitude of 0.99 (rounded to 1), successfully reaching the setpoint. It exhibits a rise time of 1.109 seconds with minimal overshoot and undershoot, both at 0.505%.
b. The comparison highlights that the LQR-controlled RF-370 DC motor system outperforms the first-order system. The LQR method enables the motor to reach the setpoint, maintain a stable step response, achieve a faster rise time, and minimize overshoot and undershoot values. These findings indicate that the application of LQR in the RF-370 DC motor significantly enhances control performance, especially in a community service context for optimizing energy systems and motor efficiency.

References

Ogata, K., 2010. Modern Control Engineering, 5th ed. Prentice-Hall, New Jersey.

Nise, N.S., 2011. Control Systems Engineering, 6th ed. Wiley, New York.

Nugraha, A.T., 2021. 'Optimal control strategies for industrial applications', Journal of Industrial Automation, 12(3), pp. 34-45.

Ahmed, S. and Lee, K., 2020. 'Application of LQR for industrial control systems', International Journal of Control Engineering, 19(2), pp. 100-110.

Jansen, R., et al., 2020. 'Development of LQR and LQT-based control systems for electric motors', International Journal of Electrical Engineering, 28(6), pp. 258-271.

Parker, M. and Miller, L., 2019. 'Advanced control systems for industrial machinery: A case study', Journal of Automation Science, 16(4), pp. 210-220.

Smith, D., et al., 2018. 'Improving motor control efficiency with LQR methods', Journal of Energy Systems, 29(7), pp. 56-65.

Wang, Y., 2021. 'Energy-efficient motor control systems: An LQR approach', Renewable Energy and Technology Journal, 17(8), pp. 123-137.

Taylor, S. and Zhang, X., 2017. 'Optimization of industrial control systems for energy savings', Journal of Smart Systems and Control, 23(5), pp. 432-444.

George, L., et al., 2022. 'Implementing linear control systems in small-scale industries', Journal of Community-Based Technology, 14(1), pp. 35-48.

Lee, J., & Chen, X., 2020. 'Optimization of DC Motor Systems Using LQR Control', International Journal of Control Engineering, 32(5), pp. 58-67.

Parker, M., et al., 2019. 'Linear Quadratic Regulator for Industrial Applications', Journal of Industrial Automation, 17(3), pp. 91-101.

Lee, T., et al., 2018. 'LQR Control System Design for Robotic Applications', Journal of Robotics Research, 45(2), pp. 123-135.

Smith, D., 2020. 'Fundamentals of Control Systems: A Practical Approach', Engineering Review, 15(1), pp. 12-20.

Johnson, M., et al., 2017. 'Control System Optimization in Electrical Motors', Journal of Power Systems, 19(6), pp. 246-258.

Hudori, M., & Paisal, H., 2019. Introduction to DC Motors. 2nd ed. Prentice Hall, New York.

Kumar, A., & Singh, P., 2020. 'Modeling and Control of DC Motors', Electrical Engineering Journal, 21(4), pp. 152-164.

MathWorks, 2019. MATLAB and Simulink for Control Systems. 5th ed. MathWorks, Natick.

White, G., & Johnson, T., 2021. Simulink for System Dynamics Modeling. 3rd ed. Springer, New York.

Marwan E. Endy, 2019. 'Numerical Processing with MATLAB in Engineering Applications', Numerical Methods Journal, 24(7), pp. 289-299.