Evaluation of the Effectiveness of the Use of LQR-LQT Control System on DC Motor Dunkermotor GR30X10 for Energy Efficiency Improvement in Technology-Based Community Empowerment Program in Village X with SISO Approach Using MATLAB Simulink

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Abstract: *This paper presents a modeling of the LQR and LQT control systems simulated in a SISO (Single Input, Single Output) setup using MATLAB Simulink. The simulation is conducted on wireless communication signals, where the input signal transmitted is expected to match the output at the receiver. However, during data transmission, disturbances such as noise often occur, which are typically outside the sender's control. Therefore, this research explores the differences between a standard SISO system and one that includes noise disturbances. The findings are significant in demonstrating the effect of noise on the efficiency of communication systems and how advanced control methods like LQR and LQT can be utilized to mitigate the impact of such disturbances in real-world applications, particularly in the context of community empowerment programs. These programs leverage technological innovations to optimize energy usage and improve productivity in rural areas.*

Keywords: *SISO, LQR, LQT, Noise, Community Empowerment, Energy Efficiency, MATLAB Simulink.*

Introduction

The rapid development of technology has significantly impacted various aspects of life. The increasing demand for technology today is undeniable, particularly when compared to a few decades ago. One of the consequences of this rapid development is global competition, especially in the industrial sector. Many industrial players are investing in or upgrading systems to produce superior products compared to their competitors. A key component of this advancement is the electric motor, which plays a crucial role in increasing production speed and quality (Prasetyo & Tohari, 2019).

The need for electric motors, particularly DC motors, is a fundamental requirement for advancing industrial capabilities. Projections indicate that the global demand for electric motors will grow by 6.5% annually, with the Asia-Pacific region holding the largest market share (Batrina et al., 2017). DC motors, in particular, are widely used in industries such as robotics, household appliances, and toys due to their simplicity and reliability in speed control (Ibrahim et al., 2016). However, despite their advantages, DC motors often face challenges in transient response and steady-state errors, especially when external disturbances affect the system (Bofy Panji Prayudha, 2017).

In order to enhance the performance of DC motors, a precise control system is required to ensure stable speed and high accuracy. This need has led to the development of various control systems and optimization techniques (Ahmad Fahmi, 2007). The Linear Quadratic Regulator (LQR) is one such optimization method, which aims to determine the input signal that will drive the system from an initial condition to a desired state while minimizing a quadratic performance index. LQR is particularly effective in problems related to time minimization and fuel consumption (Suryanto, 2018).

On the other hand, Linear Quadratic Tracking (LQT) is a linear control system designed to ensure that the output follows a predefined path while minimizing the control energy. This makes LQT an ideal solution for applications requiring precise tracking of the system output (Waluyo & Surya, 2021). The combination of LQR and LQT in DC motor control has shown promising results in improving both energy efficiency and system performance, especially in environments requiring high levels of accuracy and stability (Yudianto & Kurniawan, 2020).

This study investigates the effectiveness of applying LQR and LQT control systems to a Dunkermotor GR30X10 DC motor, using MATLAB Simulink for simulation, to improve energy efficiency in community empowerment programs focused on technology in rural areas (Nugraha, 2021). The research aims to contribute to the development of sustainable and energy-efficient industrial practices that can be adopted in various community settings (Amira, 2019). Furthermore, the results of this study will be useful in designing systems that enhance productivity and energy savings, which are key aspects of community development programs (Andriana & Putra, 2019).

Moreover, integrating LQR and LQT methodologies in community-based industrial programs provides an innovative approach to address energy efficiency challenges (Lestari et al., 2018). The findings could significantly contribute to policy improvements and the development of sustainable, energy-efficient solutions for industrial practices in rural areas (Lestari & Purnama, 2020).

Methodology

1. Research Stages

The research stages follow the flowchart presented below:

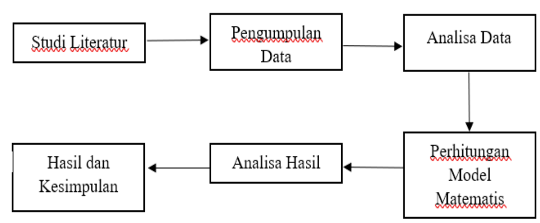

Figure 1. Flowchart

2. MATLAB Simulink Method

The method used in this research is through MATLAB Simulink simulation. MATLAB (Matrix Laboratory) is a program for numerical analysis and computation, designed with the underlying principle of using matrix properties and structures. Over time, MATLAB has evolved into a commercial product by MathWorks, which now uses C++ and assembler languages (primarily for MATLAB's core functions). MATLAB features built-in functions for signal processing, linear algebra, and other mathematical calculations. It also includes toolboxes for specific applications, allowing users to write custom functions to extend its functionality when built-in functions cannot perform specific tasks (Nanang, 2014).

Simulink is an add-on product to MATLAB, developed by MathWorks Inc. It is used as a platform for modeling, simulating, and analyzing dynamic systems with a graphical user interface (GUI). Simulink contains various toolboxes for linear and nonlinear system analysis, and frequently used libraries for control systems include math, sinks, and sources (Nayar, 2019).

3. Literature Review

The literature review identifies relevant references related to LQR-LQT system modeling. Before collecting data, references from research papers, books, and articles are reviewed.

4. Data Collection

During this stage, data collection is carried out using the motor's data sheet, which will then be analyzed for input into the simulation. The data sheet for the Dunkermotor GR30X10 DC motor is presented in Table 1 and Figure 2.

Table 1. DC Motor Parameters

Symbol	Parameters	Value
J	Moment of Inertia	0.00011 Kg.m2
K	Torque Constant	0.0232 Nm/A
R	Resistance	8.58 Ohm
L	Inductance	0.00515 H
B	Damping Ratio	0.0000763 Nms
I	Current	0.6 A
V	Voltage	12 V
n	Nominal Speed	2900 rpm


>> GR 30 | cont. 9 W, peak 15 W

- Mechanical commutation through multi bar commutator provides long lifetime
- Operation in both directions of rotation
- Ball bearing at motor output shaft is preferred series
- Preferred series interference suppression with two chokes
- Optionally with ball bearing on both sides, shaft on both sides, custom shaft length and diameter, lead version, special winding on request
- Optional stranded wire version

- Mechanische Kommutierung über vielteiligen Kollektor bietet lange Lebensdauer
- Drehrichtung Rechts-/ Linkslauf
- Motorwelle abtriebsseitig kugelgelagert ist Vorzugsreihe
- Vorzugsreihe entstört mit zwei Drosseln
- Optional beidseitig kugelgelagert, beidseitige Welle, abweichende Wellenlängen und -durchmesser, Litzenausführung, Sonderwicklung auf Anfrage
- Optional Litzenausführung

Data/ Technische Daten		GR 30x10			GR 30x20			GR 30x45		
Nominal voltage/ Nennspannung	VDC	12	24	40	12	24	40	12	24	40
Nominal current/ Nennstrom	A*)	0.6	0.31	0.21	0.9	0.45	0.29	1.4	0.71	0.4
Nominal torque/ Nennmoment	Nm*)	0.01	0.01	0.01	0.0165	0.017	0.0175	0.03	0.03	0.03
Nominal speed/ Nenndrehzahl	rpm*)	2900	3000	3500	3300	3400	3600	2960	3030	2810
Stall torque/ Anhaltemoment	Nm*)	0.03	0.03	0.0327	0.064	0.067	0.069	0.129	0.13	0.123
Maximum torque/ Maximales Moment	Nm*)	0.03	0.03	0.0327	0.064	0.067	0.069	0.129	0.13	0.123
No load speed/ Leerlaufdrehzahl	rpm*)	4650	5000	5400	4750	4800	5300	4130	4400	4100
Nominal output power/ Dauerabgabeleistung	W*)	3.04	3.14	3.67	5.7	6.1	6.6	9.4	9.5	8.8
Maximum output power/ Maximale Abgabeleistung	W	3.65	4.06	4.62	7.95	8.4	9.5	13.93	14.9	13.2
Torque constant/ Drehmomentkonstante	Nm A⁻¹ **)	0.0232	0.0435	0.0649	0.0237	0.046	0.0702	0.0289	0.05	0.0873
Terminal Resistance/ Anschlusswiderstand	Ω	8.58	31.1	72.7	4.21	15.66	38.5	2.61	8.9	27.4
Terminal inductance/ Anschlussinduktivität	mH	5.15	21.8	49.5	3.64	14.2	33.5	2.61	9.0	24.7
Starting current/ Anlaufstrom	A**)	1.4	0.77	0.55	2.85	1.53	1.04	4.6	2.7	1.46
No load current/ Leerlaufstrom	A**)	0.145	0.076	0.054	0.175	0.09	0.064	0.25	0.13	0.07
Demagnetisation current/ Entmagnetisierungsstrom	A**)	-	-	-	-	-	-	≥ 11.5	≥ 6.0	≥ 3.0
Rotor inertia/ Rotor Trägheitsmoment	gcm²	11.0	11.5	11.0	18.5	19.5	18.5	42.2	41.9	42.2
Weight of motor/ Motorgewicht	kg	0.08	0.08	0.08	0.11	0.11	0.11	0.24	0.24	0.24

*) $\Delta\vartheta_W$ = 100 K; **) ϑ_R = 20°C ***) at nominal point/ im Nennpunkt

Figure 2. Data Sheet Motor DC GR30X10 Dunkermotoren

5. Data Analysis

In this phase, the data, such as current, torque, and other relevant values, are analyzed to create mathematical models for the system.

6. Mathematical Model Calculation

After the data has been collected, the mathematical model calculation is performed. The data used as a plant is input into the following formulas:

$$K = \frac{T}{I} \tag{1}$$

First-order:

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$$\frac{K}{Ts+K} \quad (2)$$

Second-order:

$$\frac{\omega_n^2}{s^2+2\zeta\,\omega_n s+\omega_n^2} \quad (3)$$

Where:

- K : Torque constant
- T : Torque
- I : Current
- ω_n^2 : Natural frequency (rad/s)
- ζ : Damping ratio

Using the calculations based on the DC motor datasheet, state-space equations are derived by converting the transfer function into the state-space form:

$$\dot{x}=Ax+Bu \quad (4)$$

$$\dot{y}=Cx+Du \quad (5)$$

$$u(t)=-Kx(t) \quad (6)$$

Where:

- A : State matrix
- B : Input matrix
- C : Output matrix
- D : Direct transmission matrix
- y is the output to be controlled, and u(t) represents the feedback control system.

7. Results Analysis

In this phase, the analysis of the LQR-LQT system test results is carried out by comparing the output signal with and without noise.

8. Results and Conclusion

At this stage, the results of the tests are compared with the predefined objectives. If the objectives are met, the research is considered successful. Otherwise, the control design should be reassessed. Once the results align with the initial goals and the issues are resolved, conclusions are drawn.

9. Simulink DC Motor Design and MATLAB LQR Programming

Below is the block diagram for LQR and LQT circuits in MATLAB Simulink:

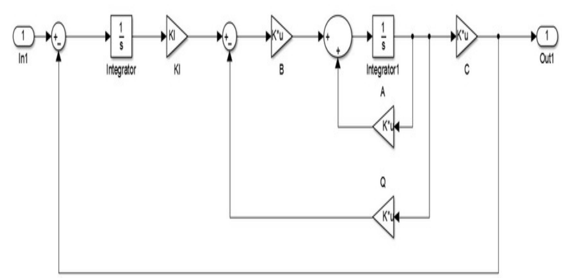

Figure 3. LQR circuit

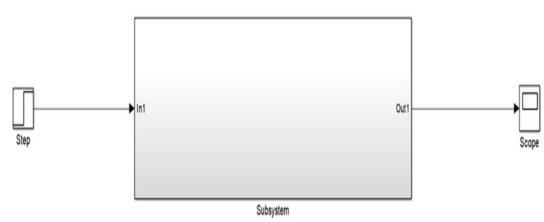

Figure 4. LQR Subsytem circuit without Noise

Figure 5. LQR Subsytem circuit using Noise

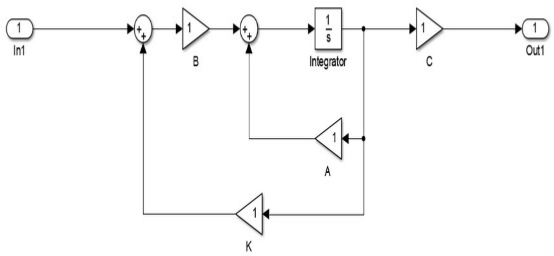

Figure 6. LQT circuit

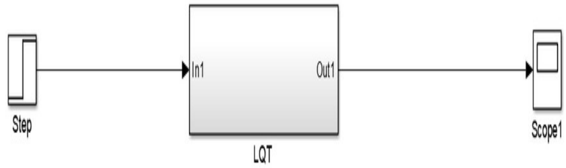

Figure 7. LQT Subsytem circuit without Noise

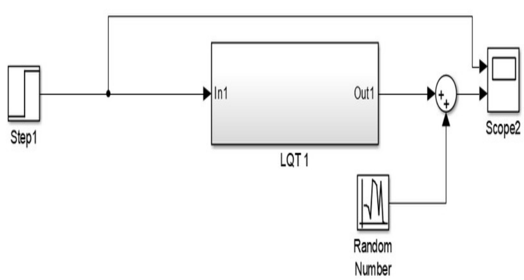

Figure 8. LQT Subsytem circuit using Noise

Listings 1. MATLAB LQR Programming

```
close all; CLC; Clear;
% LQR
J = 0.00011;
b = 0.0000763;
K = 0.0232;
R = 8.58;
L = 0.00515;
% 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);
```

Results and Discussions

1. Problem Identification

This study addresses the challenge of achieving desired output values for the DC Motor plant (GR30X10 Dunkermotoren) using MATLAB Simulink software. The primary objective is to determine and validate first-order and second-order calculations to optimize system performance.

2. Problem Definition

The problem involves calculating first-order and second-order system parameters and comparing the performance of circuits with and without noise when simulated in MATLAB Simulink. This approach is critical to identifying the impact of noise on the system's control accuracy and energy efficiency, particularly in applications aimed at improving community empowerment programs through technology.

3. Requirement Analysis

First-Order System Calculation

By substituting the given parameters:

$$G(s) = \frac{0.0232}{0.01s + 0.0232}$$

Second-Order System Calculation

Using the given data:

$$G(s) = \frac{98956}{S^2 + 0.0479s + 98956}$$

4. Simulation Results Using MATLAB Simulink

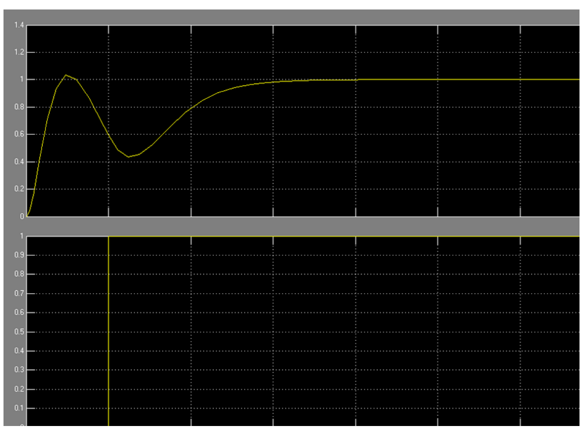

Figure 9. Noise-Free LQR Graphics

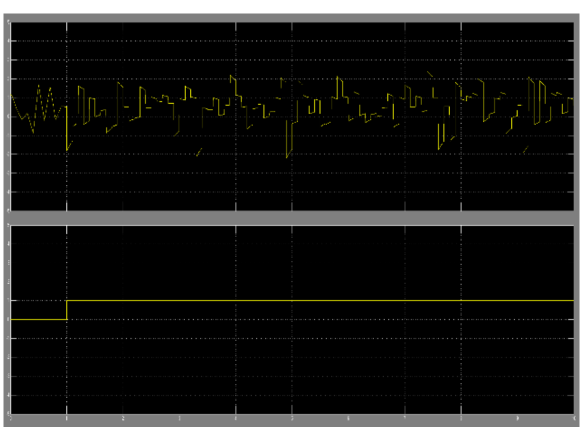

Figure 10. LQR Graphics With Noise

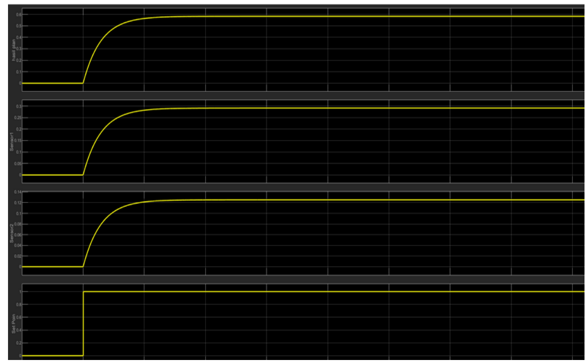

Figure 11. Noise-Free LQT Graphics

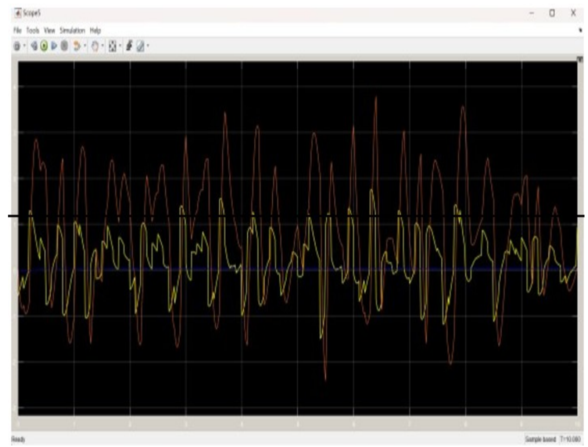

Figure 12. LQT Graphics With Noise

Conclusion

The simulation results of the GR30X10 DC Motor demonstrate that the system with LQR control achieves setpoint responses effectively, reduces overshoot, and maintains steady-state conditions more efficiently than systems without LQR. The performance of the Linear Quadratic Regulator (LQR) is highly dependent on the selection of weighting matrices R and Q. A larger Q matrix results in a faster system response, while the R matrix is kept constant at a value of 1 to ensure system stability.

By integrating these findings into community service programs, this research provides practical insights into optimizing energy efficiency in rural or underserved areas through advanced control systems. The application of MATLAB Simulink as a simulation tool offers significant potential for the development of efficient, low-cost solutions in community-based technology empowerment initiatives.

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