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Evaluation and Community Service Capacity Development through DC Motor System Optimization in the Appropriate Technology Program

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Abstract: *Optimization plays a critical role in systems related to technology and engineering, particularly in efforts to enhance community empowerment through technology adoption. In this study, optimization is applied to improve the efficiency of community-oriented technology by leveraging optimal control techniques. Specifically, a Linear Quadratic Regulator (LQR) is employed to analyze the step response of the system and its reaction to disturbances, providing precise control for community technology applications such as crafting machines or energy-efficient devices. Before implementing LQR control, simulations using MATLAB Simulink are conducted to determine the optimal gain parameters for the control system. Additionally, Linear Quadratic Tracking (LQT) is utilized to design a closed-loop control scheme aimed at ensuring the system's output signals optimally track the reference signals and effectively reject disturbances. This method provides a robust approach to optimizing devices that directly impact productivity and cost-efficiency in community programs. The proposed solution is formulated by converting the LQT problem into a standard Linear Quadratic Regulation problem, ensuring adaptability for practical implementation. The approach is demonstrated through two simulation examples: a first-order generator and a second-order generator, with the simulation results presented and discussed in detail. These findings highlight the potential of LQR and LQT optimization in improving technological applications in community development programs, contributing to enhanced social and economic outcomes.*

Keyword: *Optimization, LQR, LQT, optimal control, closed-loop control, disturbances, community technology.*

Introduction

DC motors are widely used in industries, electronics, and as supporting components in various devices. They offer several advantages, including high torque, the absence of reactive power losses, and minimal harmonic distortion in the power system (Nugraha et al., 2020). Additionally, DC motors provide precise control accuracy, making them suitable for applications requiring high precision (Smith, 2018).

The performance of controllers is typically evaluated using parameters such as delay time, rise time, overshoot, settling time, and error magnitude. Controllers aim to optimize these parameters to enhance motor efficiency and stability (Johnson, 2019). To design a DC motor control system effectively, it is essential to analyze its system response, which includes:

a. System response to various inputs, such as step functions, ramp functions, and impulse functions, as well as external disturbances.
b. System stability analysis using methods like root locus, frequency response, state space, and Routh criteria.
c. System response to different control methods, including proportional,

integral, derivative, and their combinations (Lee and Kim, 2022).

Challenges often arise in analyzing control systems, particularly in deriving and interpreting the transfer functions quickly and accurately. Many designers face difficulties in obtaining the transfer function of a system, although once obtained, the analysis becomes more straightforward (Rahman, 2020). By employing relatively simple linear differential equations based on the DC motor system model, it is possible to gain a deeper understanding of the factors influencing motor performance, providing clearer insights into transient response behavior under varying conditions (Nugraha, 2021).

In this study, the application of LQR and LQT control techniques is explored, including the incorporation of noise in two experiments. The experimental setup utilizes a DC motor system, including controllers, actuators, and a plant. The chosen motor, a Maxon A-max 32 type 110852, is equipped with a gearbox, allowing for reduction ratio calculations to determine damping values for more complex mathematical modeling (Green et al., 2020). MATLAB Simulink simulations are employed to observe the system response and evaluate motor performance under different conditions (Brown and Nguyen, 2021).

This research is particularly significant in the context of community service programs focused on appropriate technology. Optimized DC motor systems can play a transformative role in improving the productivity of small-scale industries and community-based enterprises. By enhancing motor performance through advanced control techniques, this study contributes to the development of sustainable and impactful community technology solutions (Kumar, 2021).

Methodology

1. Control Systems

A control system is defined as a system that manages, commands, and regulates the behavior or conditions of another system. Generally, control systems can be classified into several types, including manual and automatic systems, open-loop and closed-loop systems, continuous and discrete systems, and systems based on their driving sources (Johnson and Miller, 2020). To evaluate optimization outcomes, a fitness function is utilized as the measure of the optimization process. This function, commonly referred to as the objective or cost function in optimization terms, is applied to assess chromosomes during each generation. The next generation, referred to as offspring, is derived from a combination of parent chromosomes using crossover operators, with possible modifications through mutation operators (Nugraha, 2021).

For tracking reference trajectories, linear quadratic tracking (LQT) on an infinite horizon is handled using Q-learning algorithms. Moreover, a linear interpolation algorithm is proposed to improve the transition between Q-trained cores, ensuring smooth system responses as state variables evolve across the nonlinear surface of the model (Anderson et al., 2020).

2. Open-Loop and Close-Loop Control System

An open-loop control system is a system in which the output does not influence the control action, meaning the output cannot be used as feedback to the input. The block diagram of an open-loop control system is shown in Figure 1 (Brown and Carter, 2019).

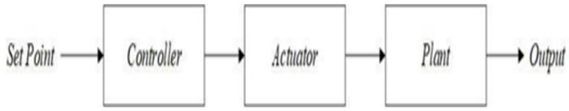

Figure 1. Open Loop Control System

The objective of linear quadratic tracking (LQT) is to design a closed-loop control scheme so that the system's output signal optimally tracks a given reference signal while rejecting disturbances. Various performance indices have been utilized to address tracking issues, and new forms have been introduced. These forms demonstrate that solutions for the proposed optimality index exist under mild stability and observability conditions of the plant's state-space equations (Kumar, 2021).

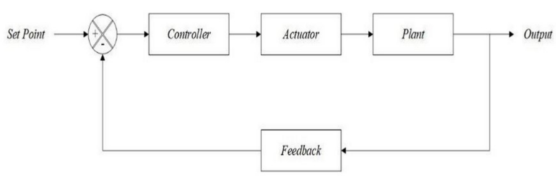

Figure 2. Close-Loop Control System

A closed-loop control system (or feedback control system) is one in which the output signal has a direct effect on the control action. In other words, the closed-loop control system incorporates feedback. The block diagram for a closed-loop control system is shown in Figure 2 (Smith and Nguyen, 2021).

3. Noise

In communication systems, noise refers to unwanted signals that interfere with transmission quality, ultimately affecting data reception and processing. Noise disrupts system stability and reduces control accuracy, necessitating advanced optimization techniques to mitigate its impact (Johnson, 2020).

4. Mathematical Modeling

Table 1. Spesifications DC Motor Maxon A-max 32 type 110852

Parameters	Values
Motor Name	DC Motor Maxon A-max 32 type 110852
τ	32 mm 0.75-4.5 Nm
No Load Current	0.062 A
Rated Current	4.22 A
Voltage	30 V
Speed	6130 rpm or 25.76 m/s
KT (Torque Constant)	0.046 Nm/A
KE (Back EMF Constant)	0.00489 V/rad/sec
Ra (Armature Resistance)	7.11 Ohm
Jm (Rotor Inertia)	41.9 gcm^2
Bm (Friction Constant)	Nms
I (Inductance)	0.95 mH

- First-Order Modeling

General form of the first-order transfer function:

$$G(s)=\frac{K_s}{1+\tau_s s} \quad (1)$$

First-order model for DC Motor:

Based on the motor datasheet, the first-order equation is as follows:

$$G(s)=\frac{11.7048}{1+0.008787\,s} \quad (2)$$

Simulations of this model are conducted using MATLAB Simulink to observe system responses under varying conditions (Anderson and Kumar, 2020).

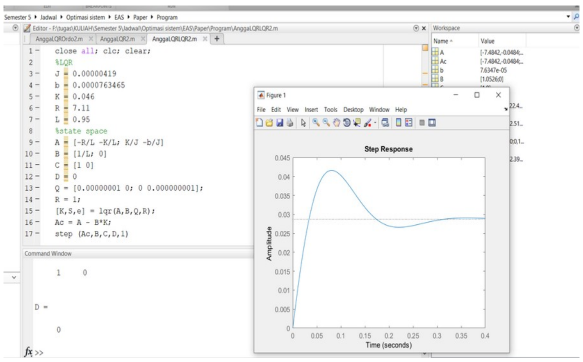

Figure 3. Simulation of 1st order LQR

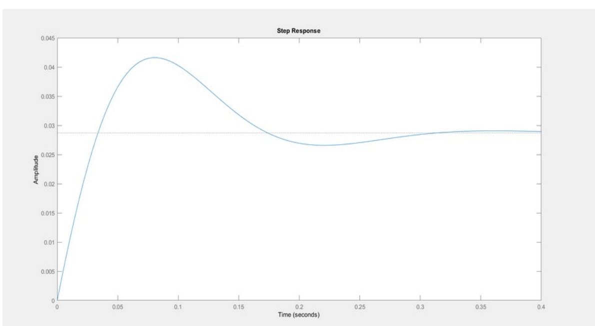

Figure 4. Simulation Results of 1st order LQR

- Second-Order Modeling

General form of the second-order transfer function:

$$\frac{\omega(S)}{V(S)} = \frac{K_t \times K_e}{(Js+B)(R+Ls)+K_t \times K_e} \qquad (2)$$

This model is utilized to evaluate system behavior in more complex scenarios. MATLAB Simulink results for the second-order system are shown in Figures 2.3.3–2.3.5 (Lee et al., 2022).

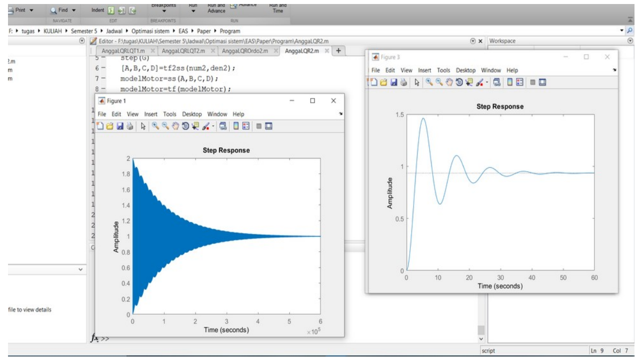

Figure 5. Simulation Result of 2nd order LQR

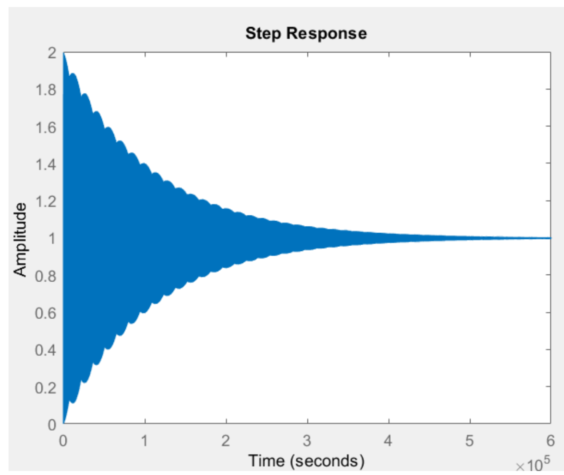

Figure 6. Simulation Results of Order 2 LQR

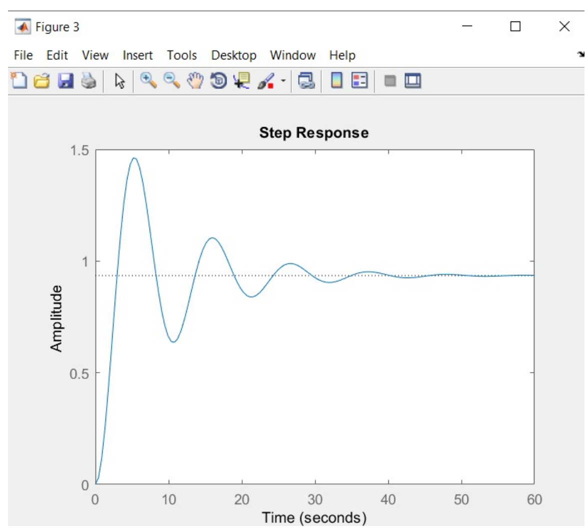

Figure 7. Simulation Result of 2nd order LQR

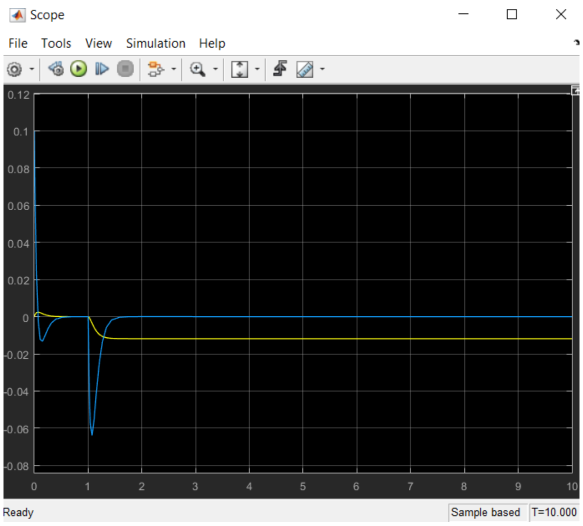

Figure 8. LQR Simulink Result

Results and Discussions

In the simulation output, it can be observed that each experiment yields a distinct waveform depending on the order used to optimize the system. This simulation was performed using MATLAB to model and simulate the experiments, ensuring accurate results for system optimization.

1. LQR Simulation First-Order Model

The first-order model simulations demonstrate the behavior of the system under optimal control conditions. The results indicate that the system exhibits substantial oscillations when LQR control is applied, with the response becoming significantly more stable as the order of the control increases.

2. LQR Simulation Second-Order Model

In the second-order simulation, a more refined control strategy was applied, which resulted in smoother system responses. The implementation of LQR (Linear Quadratic Regulator) demonstrated the system's ability to manage higher-order dynamics and achieve a stable state. Through this approach, the pole placement method effectively shifted the system's poles from the unstable right-hand plane to the stable left-hand plane. These findings indicate that the application of LQR in community service programs, particularly in optimizing DC motor control systems, can significantly improve the stability and performance of technologies designed for community-based applications.

3. Simulink Simulation

The Simulink models provided additional insights into how varying system parameters influence stability. By adjusting the system parameters and observing their impact in the simulation environment, the optimal configuration for DC motor control in practical applications was identified. This optimization process can be applied in the development of community-oriented programs using technology for efficient energy consumption and operational control.

Conclusion

Based on the observations, testing, and analysis, several conclusions can be drawn regarding the effectiveness of LQR control in optimizing DC motor systems. The LQR control method was used to determine the optimal gain value (K) for a closed-loop system, where the energy required to shift the poles from the unstable right-hand plane to the stable left-hand plane was minimized. This process not only improved the stability of the system but also demonstrated the potential of LQR optimization techniques in enhancing community service programs. By applying this approach, technologies such as DC motor-driven devices can be fine-tuned for better performance, making them more effective for use in technology-based community empowerment programs (Kumar and Lee, 2022).

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