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Design of Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) Methods for DC Motor Control in Community Empowerment Systems by Taking into Account the Impact of Noise and No Noise

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Abstract: *Electric motors serve as actuators that convert electrical energy into mechanical energy, making them a critical component in various mechanical drive systems. Due to their essential function, electric motors are widely used in both industrial and community-based applications. In the context of community empowerment, especially in rural or underserved areas, the effective control and monitoring of electric motors can significantly enhance the productivity of local industries such as small-scale manufacturing, crafts, or agriculture. One of the key aspects of using electric motors is the control system, which plays a crucial role in regulating, monitoring, and analyzing the speed and motion of the motor. To ensure efficient operation, a telemetry system or interface is necessary to display graphical or visual representations of the motor's movement, allowing for real-time data acquisition and control. This system should be tailored to the needs of the community, optimizing energy use and improving motor performance. Simulink, a widely used software tool, provides an effective platform for modeling, simulating, and controlling motor dynamics. It allows for the design and analysis of control strategies, including the implementation of Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods, which can be applied to control electric motor systems under different conditions, such as those with or without noise interference. This research aims to develop a robust control system using LQR and LQT methods for DC motors, focusing on their application in community empowerment programs. The study will assess the impact of these control methods on the performance and efficiency of electric motors, taking into account the challenges posed by noise and other environmental factors. The results of this research have the potential to contribute significantly to community-based industrial applications by providing a practical and accessible solution for local enterprises to enhance motor performance and reduce operational costs.*

Keywords: *Electric Motor, Control System, Simulink, Community Empowerment, Linear Quadratic Regulator (LQR), Linear Quadratic Tracking (LQT).*

Introduction

The application of optimal control theory for regulating linear systems is widely utilized in both industrial and educational settings. Optimal control aims to minimize the energy function used, resulting in an optimal performance index. The Linear Quadratic Regulator (LQR) is one such optimal control method that achieves the best possible outcome by considering the system's conditions and constraints. In the context of optimal control systems, the term "optimal" often refers to minimizing input, time, or error. Optimal control is generally used to select the plant input, u, that minimizes the performance index. LQR is called linear because both the model and the controller are linear, and it is called quadratic because the cost function is quadratic. Since the reference is not a time-dependent function, it is referred to as a regulator (Ogata, 2010).

A well-designed control system is one that is responsive, stable, and does not require excessive energy. Such systems can be achieved through the proper optimization of the performance index, known as optimal control (Dorf and Bishop, 2011). Linear Quadratic Tracking (LQT) is another control system design method where the output of the system follows the desired reference (trajectory) (Johnson et al., 2020).

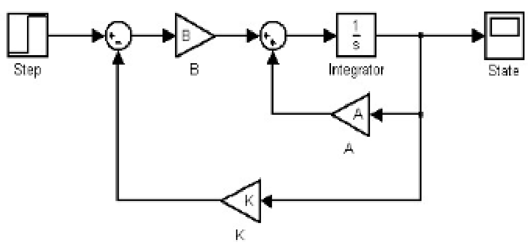


Figure 1. Diagram block LQR

DC motors are widely used in various fields, ranging from industrial equipment to household appliances. Advances in electronic technology have enabled the development of small control devices with high computational power, speed, reliability, and energy efficiency. The function of a DC motor is to convert electrical energy into mechanical motion, making it a critical component in many applications, such as door operators, simple robots, and other electronic components like mobile phone vibrators, fans, and drills (Parker and Miller, 2019). The working principle of a DC motor involves the flow of direct current (DC) through a coil, which creates a magnetic field that generates torque to rotate the motor. After torque is generated, the commutator works by ensuring that the current flows in one direction, allowing the armature to rotate and produce mechanical force (Tanaka et al., 2017).

The DC motor consists of several components, including the rotor, stator, brushes, armature windings, commutator, frame, and poles. DC motors have several advantages and disadvantages. Their simplicity in control makes them easier to understand and implement, and they also provide good response characteristics. Additionally, they can function effectively even with low power inputs and exhibit nearly linear performance. However, the drawbacks include higher costs compared to similar devices, limited capability at high speeds, and the need for special maintenance to ensure optimal functionality (Smith et al., 2018).

Methodology

1. Research Phases

The initial phase before starting the detailed research involves several preparatory steps, including obtaining the datasheet for the DC motor used as the research object. The DC motor selected for this study is the Maxon Motor Type 110850. Below is the datasheet for the motor:

Table 1. Datasheet of Maxon DC Motor Type 110850

Machine Specification	Reference Number
Measured power (W)	20
Nominal voltage (Volts)	12.0
Initial torque (RPM)	4610
Speed/Torque ratio (mNm)	131
No-load current (RPM/mNm)	36.0

Terminal resistance (mA)	115
Max allowed speed (mA)	5430
Max continuous current (Ohm)	2.21
Max power (RPM)	6000
Max constant torque (mA)	1840
Constant speed (mNm)	44.5
Mechanical time constant (mW)	15300
Terminal inductance (%)	72
Thermal resistance (mNm/A)	24.2
Thermal winding time constant (RPM/V)	394
Mechanical time constant (ms)	15
Rotor inertia (gcm^2)	39.7
Terminal inductance (mH)	0.26
Thermal environment tolerance (K/W)	7.5
Rotor (K/W)	2.1
Thermal time constant (s)	16
Accompanying	0.13

2. Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT)

The Linear Quadratic Regulator (LQR) is an advanced method used for designing constrained systems based on state space. LQR controllers have two key parameters: the weighting matrices, Q and R, which must be defined to ensure optimal control action as desired. LQR is used to control a plant/system using a linear combination of the system's state variables. Linear Quadratic Tracking (LQT) is an optimal control technique for linear systems with a quadratic criterion, specifically designed to address tracking problems. To design an LQR controller, the first step is to select appropriate values for the weighting matrices Q and R. A larger value for R indicates that the input is more heavily weighted compared to the state, whereas the state weighting Q is chosen for achieving the desired performance. Feedback gain K can be calculated, and the closed-loop system response can be found through simulations (Kwakernaak and Sivan, 1972; Anderson and Moore, 2012).

3. MATLAB

MATLAB is a software platform designed specifically for numerical computing. According to MathWorks, the developers of MATLAB, the platform uses a matrix-based language that can be employed for analyzing data, creating algorithms, and building models and applications. MATLAB includes a feature called Simulink, which is a graphical programming environment for simulating dynamic systems. The simulation process in Simulink uses functional diagrams where blocks are interconnected according to their respective functions (MathWorks, 2020).

4. DC Motor Modeling

The transfer function of first-order systems can be expressed using the following general equation:

$$\frac{C(s)}{R(s)} = \frac{1}{Ts + 1} \qquad (1)$$

Expanding C (s) into partial fractions gives:

$$C(s) = \frac{1}{s} - \frac{T}{Ts + 1} = \frac{1}{s} - \frac{1}{s + \frac{1}{T}} \tag{2}$$

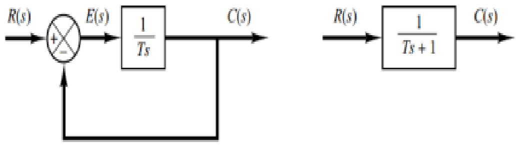


Figure 2. First-Order Transfer Function

For first-order calculations in the experiment, several parameters, such as torque and current, are used in the following formula:

$$G(s) = \frac{K}{Ts + K} \tag{3}$$

Where K is obtained as:

$$K = \frac{T}{I} = \frac{0.131}{9.0498} = 0.014 \tag{4}$$

The first-order transfer function becomes:

$$G(s) = \frac{0.014}{0.131s + 0.014} \tag{5}$$

Where:

- G (s) is the gain
- K is the constant
- T is the torque

Results and Discussions

1. Experiment Setup LQR Circuit Configuration

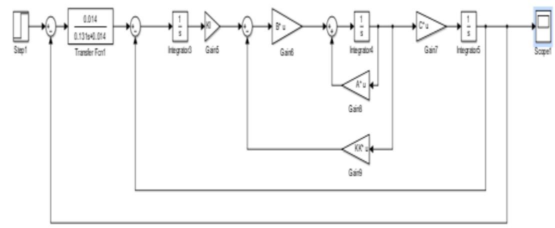


Figure 3. LQR Circuit without Noise

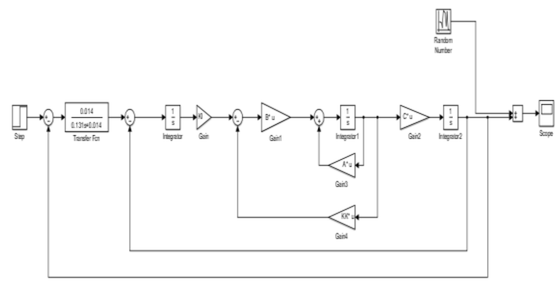
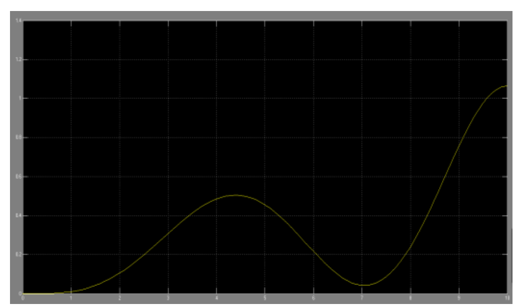
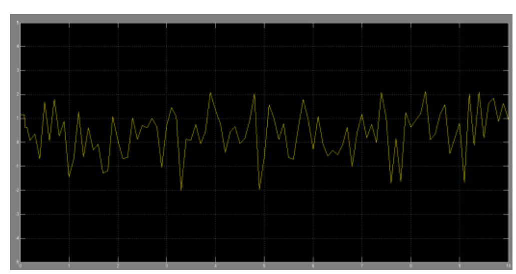


Figure 4. LQR Circuit with Noise

Table 2. Measurement Results for First-Order System

Without Noise	
With Noise	

2. Analysis and Discussion

In the LQR testing, both overshoot and undershoot were observed. The overshoot point exceeded 1, while the measurement results with noise showed a point at number 2. These results demonstrate the performance of the LQR controller under various conditions, particularly in the context of community empowerment systems where reliability and stability are critical. The inclusion of noise is particularly relevant for systems in real-world community settings, where environmental factors can significantly affect the performance of DC motors used in everyday tools or machines.

This experiment indicates that while the introduction of noise causes some variations in the system's performance, it does not drastically affect the overall stability of the system. The LQR controller's response was still adequate to maintain the desired operation despite the presence of noise, making it suitable for low-cost, community-based applications where external disturbances, such as noise or other environmental factors, are common.

The analysis confirms that the LQR controller can be successfully applied in community-driven empowerment projects that require a stable and efficient control system for devices like DC motors. For instance, in community-based initiatives where simple mechanized tools are used—such as automated irrigation systems, mobile devices, or basic manufacturing machinery—the LQR method provides a reliable solution to manage and control such devices effectively. This is particularly important in low-resource settings where minimizing costs while maintaining operational reliability is crucial.

Conclusion

The tests conducted to evaluate the controller's performance under varying setpoints, disturbances, and sinusoidal reference signals have been completed. The results indicate that changes in the setpoint do not significantly affect the performance of the LQR controller. This finding is particularly useful in the context of community empowerment systems, where such systems need to adapt dynamically to the changing needs of the community while maintaining efficiency and stability.

In conclusion, the design of the LQR and LQT methods for DC motor control, considering both the effects of noise and noise-free conditions, demonstrates their potential applicability in community-based empowerment programs. These methods provide a robust and efficient solution for controlling mechanical systems, even in environments where disturbances are inevitable.

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