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Optimization of DC Motor 80BL Using LQR Methods on MATLAB Simulink for Community Empowerment Applications

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Abstract: *Optimization techniques are essential tools for achieving the best possible outcomes in various fields, from engineering and economics to social sciences, including community empowerment. These techniques allow for optimal decision-making processes, especially in situations requiring minimal costs and maximum benefits. In the context of community service and empowerment, optimization techniques can enhance local initiatives, such as small-scale manufacturing, agricultural processes, and the development of community-based enterprises, by improving efficiency and reducing unnecessary costs. For example, in the design of infrastructure projects or the optimization of energy distribution systems, optimization techniques ensure that resources are used effectively to serve the community's needs. Moreover, by applying optimization methods, communities can enhance their self-sufficiency and contribute to sustainable development. The ability to minimize costs while maximizing utility can be a game-changer, particularly in underdeveloped areas where resources are limited. This research focuses on the optimization of a DC Motor 80BL using Linear Quadratic Regulator (LQR) methods on MATLAB Simulink, offering an advanced solution for community empowerment applications. LQR provides an optimal input that results in state feedback, represented by a constant gain within the system's state, which can significantly improve the efficiency of various mechanical systems used in community-driven projects. The application of these optimization methods in community development ensures that local industries and projects can operate at their highest potential.*

Keyword: *Optimization, system, mathematical, LQR,*

Introduction

The rapid advancement of technology in the modern era plays a crucial role in human life, greatly assisting various activities to become more effective and efficient. One of the most significant sectors that benefit from technological development is industry[1]. In particular, technological progress in the industrial sector has a direct impact on economic growth, as industry plays an essential role in processing resources to meet the needs of society.

In the industrial resource processing process, especially in manufacturing industries, several core tools are required to support production activities, one of which is the DC motor[2][3]. The application of DC motors in various fields, such as industry and robotics, is widespread. They are used in a variety of machines and processes, including pump impellers, compressors, mixers, electric trains, elevators, mining machinery (such as coal mining equipment), mobile phone vibrators, household appliances, disk drivers, DC electric drills, DC fans, printers, robotic arms used in car assembly, and paper-cutting machines.

DC motors are favored over AC motors due to their ease in speed regulation and simpler structure [4]. One of the methods to control the speed of a DC motor is by adjusting the input voltage. Speed regulation is an essential factor in the operation of DC motors; however, the rotational speed can decrease and become inconsistent due to load variations. To address this, a speed control system design is necessary to maintain the desired speed of operation. However, external and internal disturbances can affect or reduce the performance of DC motors[5]. These disturbances may lead to motor failure, which can severely disrupt the operation of systems dependent on them. Common causes of motor failure include heat, dirt, humidity, vibration, and electrical quality issues.[6] Poor maintenance, such as improper lubrication and insufficient cleaning, are additional contributing factors.

In the context of community empowerment, ensuring the reliability of DC motors is crucial for various community-driven projects that involve machinery or tools. By applying optimization techniques, such as Linear Quadratic Regulator (LQR) methods, the performance of DC motors can be improved to support local initiatives, like small-scale manufacturing, energy distribution, or agricultural applications. These technologies help optimize energy use and enhance efficiency, making them valuable in community development projects where limited resources must be maximized[7][8].

One critical component in control systems is the actuator. An actuator is a device that converts electrical energy into mechanical energy, enabling movement. In a DC motor, this conversion occurs when electrical energy is supplied to the armature and field coils, generating mechanical motion. The field coils, known as the stator (the stationary part), and the armature coils, known as the rotor (the rotating part), are essential for the functioning of the motor. In community empowerment applications, the use of DC motors, coupled with appropriate control systems, can drive critical processes, such as power generation, water pumping, or even the operation of tools for local crafts and manufacturing.

Methodology

1. LQR

   Linear Quadratic Regulator (LQR) is a mathematical optimization approach designed to determine the optimal sequence of control inputs for linear systems[9]. The primary goal of LQR is to minimize a quadratic cost function (integral) that could potentially lead to excessive values if left unchecked, ultimately aiming for the most efficient and stable system performance. From a theoretical standpoint, the fundamental property of LQR is its ability to generate optimal inputs that provide state feedback, which can be represented as a constant feedback gain applied to the system's state[10].

   When applied to community empowerment projects, LQR offers significant potential in optimizing systems that rely on mechanical and electrical processes, such as motors used in small-scale industries, water pumping systems, and renewable energy projects. For instance, in rural communities, where access to resources may be limited, applying LQR can optimize motor performance in various equipment, like pumps for irrigation or machines used in local production, ensuring these systems operate at peak efficiency with minimal resource wastage[11][12].

- Cost Function

$$J = \int_{0}^{\infty} (x^T Q x + u^T R u) dt$$

Q = state weighting factor
R = Control variable factor weights
u = Singal control
optimal K value of the performance index

$$K = R^{-1} B^T P$$

Where the matrix P in the equation above must satisfy the reduced equation

$$A^T P + PA - PBR^{-1} B^T P + Q = 0$$

LQR's ability to continuously adjust the control signals based on real-time feedback makes it a valuable tool for maintaining stable and efficient operations in community-driven initiatives[13]. This capability is especially crucial in settings where external factors such as power fluctuations, mechanical wear, or environmental conditions can disrupt system performance. By optimizing motor speed and power usage, LQR ensures that local businesses and community infrastructure can operate sustainably, improving overall productivity and economic stability.

Moreover, LQR and its extensions offer a sophisticated yet accessible approach to addressing the challenges faced in community empowerment initiatives, where technological solutions are often implemented to improve daily life[14]. Whether it's enhancing the efficiency of agricultural tools, improving local manufacturing processes, or ensuring consistent energy distribution, the application of LQR can play a crucial role in increasing the impact of community-driven technological solutions, thereby contributing to social and economic development.

2. Simulink Matlab

MATLAB is a software platform used for programming, analysis, and technical and mathematical computations based on matrices. The name MATLAB stands for Matrix Laboratory because it is designed to solve various matrix-based problems[15]. A primary feature of Simulink, an add-on product for MATLAB, is its ability to create dynamic system simulations. Simulations are conducted using functional diagrams consisting of blocks that are interconnected according to their respective functions. MATLAB was first introduced by Cleve Moler in 1970. Initially, MATLAB was used to solve algebraic linear equations. However, over time, the software has evolved significantly, expanding both in terms of functionality and computational performance[16].

Today, the MATLAB programming language is developed by MathWorks Inc., and it integrates programming, computation, and visualization within an easy-to-use environment. MATLAB offers several other notable advantages, such as data analysis and exploration, algorithm development, modeling and simulation, 2D and 3D plotting visualizations, and the creation of graphical user interfaces. Within academic institutions, MATLAB is widely used as a tool for teaching mathematics, engineering, and science programming, both at introductory and advanced levels. In the industrial sector, MATLAB is chosen as a powerful tool for research, development, and product analysis.

In the context of community empowerment, MATLAB can play a significant role in enhancing local technological capabilities. For instance, community-based organizations can use MATLAB and Simulink to optimize mechanical systems such as motors and pumps, which are essential in agriculture, water distribution, and small-scale manufacturing in rural or underserved areas. By leveraging MATLAB's capabilities, local stakeholders can simulate, model, and optimize systems, ensuring that they function efficiently and sustainably within the constraints of available resources. This is particularly crucial in rural communities where access to advanced technological tools is limited, and efficient use of resources can lead to substantial improvements in local development.

Before conducting the research, the authors identified key challenges in controlling position systems in SISO (Single Input Single Output), SIMO (Single Input Multiple Output), MISO (Multiple Input Single Output), and MIMO (Multiple Input Multiple Output) systems, which are vulnerable to disturbances that may prevent the system from maintaining the desired position. Therefore, a comprehensive plan was developed to ensure that this research aligns with the initial expectations and objectives, aiming to provide practical, applicable solutions for real-world community empowerment efforts[17][18].

3. Mathematic Model

Mathematical modeling is a technique for representing a complex system in a mathematical model[19]. In other words, mathematical modeling is a system of equations that can represent a complex problem being observed. In this way, the formulated mathematical model is expected to be able to explain the complex situation being observed. In general, the form of a 1st order system can be written as follows:

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

Meanwhile, the general form of the 2nd order system can be expressed in the following standard form:

$$G(s) = \frac{\omega n^2}{s^2 + 2\tau\omega n s + \omega n^2}$$

Where :

K = Coefisient
τ = Torque

ωn = frequency

- Ordo 1
  1st Order DC Motor Based on the DC motor datasheet, the 1st order equation is obtained:
  Where τ= K.i so

$$K = \frac{\tau}{i} = \frac{3}{5} = 0{,}6$$

$$so\ the\ ordo\ 1\ is:$$

$$G(s) = \frac{0{,}6}{3s+1}$$

- Ordo 2

$$G(s) = \frac{(314)^2}{s^2+2(3)(314)s+(314)^2}$$

$$G(s) = \frac{98596}{s^2+(6)(314)s+98596}$$

$$G(s) = \frac{98596}{s^2+1884s+98596}$$

4. SISO (Single Input Single Output)

SISO (single input single output) is a simple single variable control system that uses one input and produces one output.

Figure 1. Simulation SIMULINK

In the picture above, it can be explained that a SISO system has input which is then managed by a controller whose job is to control the system to achieve output values that match the input provided[20]. After passing through the controller, it goes to the Target System or what we usually call the actuator and plant as the controlled control variable. The output from the Target System action will be given feedback to a sensor or transducer to measure whether the output from a plant is in accordance with a predetermined setpoint. If it is not appropriate, the measurement results will be processed again in the controller to control the Target System so that it has an output that matches the desired setpoint

Results and Discussions

1. Program for script Marlab:

```
close all; clc; clear;
%LQR
J = 0.000016 %J=momen inersia
b = 0.0000963 %b=damping ratio
K = 0.03 %K=Konstanta torsi(Kt)
R = 1.09 %R=resistansi
L = 0.016 %L=induktansi

%mencari (b)
%b= T/w
%b= 0.052/540.08
%w = 2xpi (n/60)
%w = 2x3.14 (5160/60)
%n = speed motor RPM

%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);
```

2. Simulink Circuit

Figure 2. SIMULINK circuit

3. Result

- Ordo 1

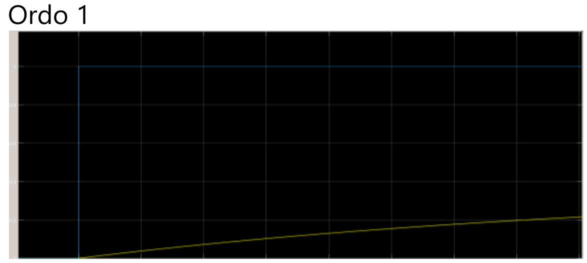

Figure 3. Ordo 1 SISO Result

Based on the results that have been displayed, it can be said that the output of the 1st order SISO DC motor has not yet reached the desired set point. The blue graph is the input value of the step. Meanwhile, the yellow graph is the output of the 1st order SISO DC motor. The desired set point value is 1, but the output value of the SISO order 1 DC motor only reaches 0.2.

- Ordo 2

Figure 4. Ordo 2 SISO result

Based on the results that have been displayed, it can be said that the output of the second order SISO DC motor has not yet reached the desired set point. The blue graph is the input value of the step. Meanwhile, the yellow graph is the output of the 2nd order SISO DC motor. The desired set point value is 1 but the output value of the 2nd order SISO DC motor only reaches 0.5. However, the output value of the SISO Order 2 DC motor is closer to the desired set point compared to the output value of the SISO Order 1 DC motor.

Conclusion

The conclusion drawn from the mathematical modeling analysis of the DC Motor 80BL Series highlights the critical importance of utilizing transfer functions derived from first-order and second-order DC motor modeling in Simulink simulations conducted using MATLAB software. These transfer functions play a pivotal role in analyzing the step response of the DC motor system configured under SISO (Single Input Single Output), SIMO (Single Input Multiple Output), MISO (Multiple Input Single Output), and MIMO (Multiple Input Multiple Output) frameworks. Each motor model is designed to achieve specific setpoints, although not all models perfectly meet the desired objectives.

The calculation process for the mathematical models of first-order and second-order systems is based on data sourced from the motor's datasheet, which simplifies the formulation of transfer functions. Further analysis reveals that the second-order model consistently delivers responses that are closer to or more accurately aligned with the predetermined setpoints compared to the first-order model. This demonstrates the superiority of the second-order model in accurately reflecting the dynamic behavior of the DC motor system.

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