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ENHANCING THE PERFORMANCE OF THE PG45RS775 DC MOTOR THROUGH LQR AND LQT OPTIMIZATION

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ABSTRAK

Sistem kontrol memainkan peran penting dalam meningkatkan efisiensi proses manufaktur selama revolusi industri keempat. Pencarian kontrol optimal menjadi fokus selama periode ini, didorong oleh permintaan yang terus meningkat untuk sistem berkinerja tinggi. Dua metode, yaitu LQR (linear quadratic regulator) dan LQT (linear quadratic tracking), umum digunakan untuk mencapai hasil optimal. Dalam eksperimen yang melibatkan motor DC, teramati bahwa LQR mencapai set point yang diinginkan dengan overshoot yang lebih rendah dibandingkan LQT. Selain itu, dalam sistem kontrol, kehadiran noise, atau gangguan, dapat memengaruhi output sistem. Pengenalan noise baik pada sistem LQR dan LQT secara signifikan memengaruhi output, menyebabkan peningkatan overshoot yang signifikan pada sistem.

Kata Kunci: *LQR, LQT, Noise*

ABSTRACT

The control system played a crucial role in enhancing the efficiency of a manufacturing process during the fourth industrial revolution. The pursuit of optimal control became a focal point during this period, driven by the growing demand for high-performance systems. Two methods, namely LQR (linear quadratic regulator) and LQT (linear quadratic tracking), are commonly employed to achieve optimal results. In the conducted experiment involving a DC motor, it was observed that LQR achieved the desired set point with a lower overshoot compared to LQT. Additionally, in control systems, the presence of noise, or disturbances, can impact the system's output. The introduction of noise to both the LQR and LQT systems significantly influenced the output, leading to a notable increase in overshoot in the system.

Keyword *: LQR, LQT, Noise*

1. INTRODUCTION

Authors With the advancement of science and technology [1], both manual and automatic control systems have gained significant importance [2]. The role of automatic control systems is particularly pronounced in fulfilling various human needs and in nations that have advanced their civilizations [3]. Additionally [4], in the context of the fourth industrial revolution [5], control systems play a crucial role in enhancing the effectiveness and efficiency of production processes [6]. An optimal system offers numerous advantages in decision-making and finds applications across diverse fields of science [7], including engineering, economics, policing, politics, and social sciences [8]. Examples of such applications range from civil or mechanical construction design, network maintenance [9], and the control systems and operation of electrical machinery to electrical power distribution [10]. In these applications, optimal decision-making is essential to achieve minimal cost expenditures with maximum utilization [11]. The current emphasis on optimal control arises from the growing demand for high-performance systems [12]. The optimization of control systems involves choosing performance and engineering indices to create an optimal control system within the confines of physical constraints [13]. When addressing optimal control systems, the goal is to establish a decision-making rule that minimizes the deviation from the ideal behavior of the control system [14]. Typically, this optimization system relies on mathematical programming techniques, which often involve discussing or referencing the ongoing research programming related to the specific problem [15]. The expectation is that this technique will yield the best solution based on the decisions made in addressing the problem at hand [16]. Presently, there exist numerous approaches to achieve optimal system performance. In this simulation, we will employ the LQR and LQT methods on the PG45RS775 DC motor with the aim of attaining maximum rotation [17]. The selection of LQR and LQT is based on their ability to address significant disturbances impacting system stability without compromising operational efficiency, and they can swiftly overcome prior disturbances [18].

2. DISCUSSION

2.1 Methodology

The research phases are instrumental in outlining the progression of the research to attain the desired outcomes, which will be elucidated through a flowchart system [19].

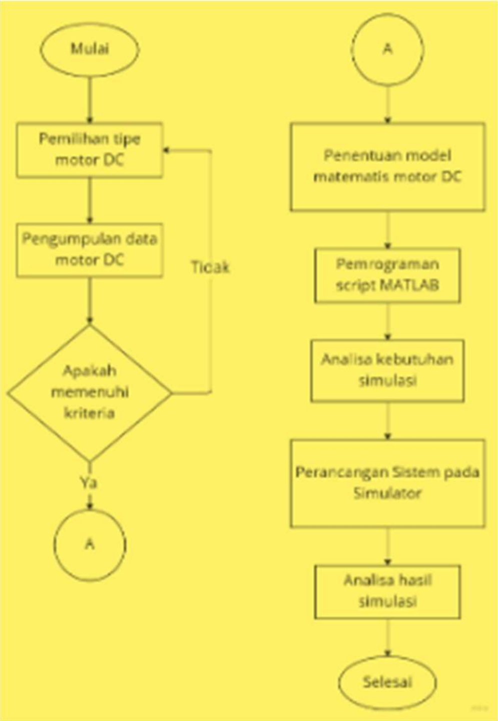
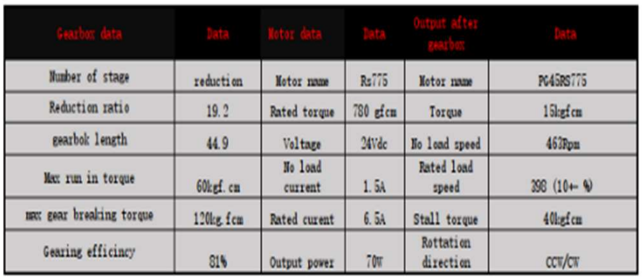


Figure 2.1 Research flow chart

2.2. Information Sheet and Specifications of DC Motors



Gearbox data	Data	Motor data	Data	Output after gearbox	Data
Number of stage	reduction	Motor name	Rs775	Motor name	PG45RS775
Reduction ratio	19.2	Rated torque	780 gfcm	Torque	15kgfcm
gearbok length	44.9	Voltage	24Vdc	No load speed	463Rpm
Max run in torque	60kgf.cm	No load current	1.5A	Rated load speed	398 (10+- %)
max gear breaking torque	120kg.fcm	Rated curent	6.5A	Stall torque	40kgfcm
Gearing efficincy	81%	Output power	70W	Rottation direction	CCW/CW

Figure 2.2 Datasheet Motor DC PG45RS775

Name Motor = Motor DC PG45RS775
τ (Torsi) = 15 kgfcm = 1,47 N/m
No load current = 1,5A
Rated Current = 6,5A
Voltage = 24V
Speed = 500 rpm atau 52,36 m/s
Diameter = 34 mm = 0,034 m
Rad Motor = 17 mm = 0,017 m

2.3. Modelling DC Motors Mathematically

A mathematical model is a straightforward depiction of a problem or occurrence, articulated through mathematical concepts [20]. Starting with a given problem or phenomenon, a simplified and easily solvable mathematical equation is derived [21]. The transfer function is a ratio between the Laplace function of the output and the Laplace function of the input, assuming all initial conditions are zero [22]. It is employed to facilitate the analysis of a system's characteristics, providing a clearer understanding [23].

Broadly speaking, the structure of a first-order system can be expressed as:

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

For a first-order DC motor derived from the PG45RS775 DC motor datasheet, the equation takes the form:

$$G(s) = \frac{0.226}{\pi s+1}$$

Here, K is the DC motor coefficient, τ is the DC motor torque, and I represent the DC motor current, where $K = \frac{1.476}{6.5} = 0.226$.

To derive the first-order equation for the DC motor, the expression is:

$$G(s) = \frac{0.226}{1.47s+1}$$

Regarding the general configuration of a second-order system, it can be represented in the standard form:

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

Derived from the DC motor datasheet, the second-order equation for the DC motor is obtained as follows:

The transfer function G(s) is expressed as $(2\pi \times 50)^2 s^2 \;+\; 2.19\times 2\pi \times 50 \;\times 2.314s \;+$

$(2\pi \times 50)^2$, which simplifies to $98956s^2$ + 120575s + 98956. In this equation:

ω_n^2 Represents the natural frequen

δ is the damting ratio

2.4. LQR (Linear Quadratic Regulator)

Linear Quadratic Regulator (LQR) is a contemporary control method employing the state space approach [24]. This controller relies on two essential parameters, namely the weight matrices Q and R, whose determination is crucial for achieving the intended control action [25]. The Q and R matrices are strategically weighted to elicit a control response aligned with the specified control requirements [20]. The control system under consideration is represented by the following equation:

$$\dot{x} = Ax + Buy = Cx$$

The optimization approach utilizing a linear quadratic regulator aims to ascertain the input signal required to transition a linear system state from the initial condition $x(t0)$ to a final state $x(t)$, minimizing a quadratic performance index [JM electro]. This performance index is a function of a cost, reflecting the degree to which the actual system performance aligns with the desired performance [20]. The relevant cost function involves the time integral of the quadratic form applied to the state vector x and u, as expressed in the equation:

$$J = \int_0^{\infty} (x^T Q x + u^T u R)\, dt$$

The matrices Q and R are integral to the linear quadratic regulator, with Q being a positive definite real (or positive semidefinite) symmetric matrix, and R being a positive definite real symmetric matrix. These matrices play a crucial role in defining the significance of error and energy considerations [23].

The fundamental concept behind the LQR method is to derive the optimal control signal through state feedback, ensuring optimal control signal generation [17].

U = -Kx

2.5. Matlab Script for Linear Quadratic Regulator (LQR)

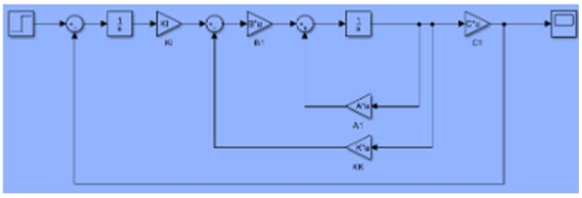


Figure 2.3 Matlab Simulink LQR

2.6 LQT (Linear Quadratic Tracking)

Linear Quadratic Tracking (LQT) is an optimal control technique designed for linear plants, specifically addressing tracking challenges within a regulatory system where the output is configured to follow a predetermined path through input [15]. The overall structure of the linear system state equation is depicted in the following equation:

$$\dot{x} = Ax + Buy = Cx$$

In addition to having a state equation, a system also possesses an error vector, as represented by the following equation:

$$e(t) = z(t) - y(t)$$

The objective of LQT is to ensure that the system output closely tracks the reference model output while minimizing the specified performance index. The performance index is defined by the following equation:

$$J = \frac{1}{2}\, e'(t_f)F(t_f)e(t_f) + \frac{1}{2}\int_{t0}^{t} [e'(t)Q(t)e(t) + u'(t)R(t)u(t)]\, dt$$

Suppose F(tf) and Q(t) are matrices of dimension (m x m) that are symmetric and positive semidefinite. Additionally, R(t) is a positive definite symmetric matrix of dimension (R×R). The matrices Q and R serve as weight matrices, influencing the performance of the controlled system.

Once the mathematical model of the system is derived in the form of statespace and matrices A(t) and B(t), the solution matrix for the Riccati differential equation in the finite-time scenario can be determined using the following equation:

$$P(t) = - P(t)A(t) - A'(t)P(t) + P(t)B(t)R^{-1}(t)B'(t)P(t) + C'(t)Q(t)C(t)$$

Similarly, for the infinite-time scenario, the solution matrix for the Riccati differential equation can be found using the following equation:

$$0 = -P(t)A(t)-A'(t)P(t) + P(t)B(t)R^{-1}(t)B'(t)P(t) + C'(t)Q(t)$$

The matrices Q and R can be chosen based on the desired system performance. Once the Riccati equation is acquired, the non-homogeneous vector differential equation can be determined using Eq.

$$\dot{g}(t) = -[A(t) - B(t)R^{-1}(t)B'(t)P(t)]'+C'(t)Q(t)z(t)$$

Upon obtaining the symmetric positive definite matrix P(t) and g(t), the feedback gain values K(t) and u*(t) can be determined using the Riccati equation:

K(t) = R-1(t)B'(t)P(t)

$$u^*(t) = -K(t)x^*(t) + R^{-1}(t)B'(t)g(t)$$

The equation above yields a constant matrix value K that remains unchanged as a function of time.

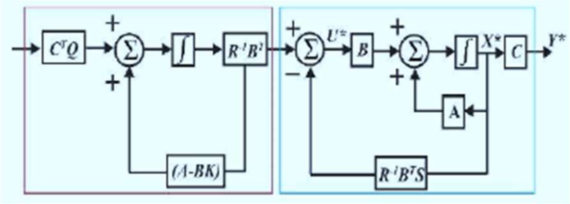


Figure 2.4 Blok Control LQT

The red block represents the LQT model, while the blue block signifies the control block in the system.

2.6. Noise in the Network

Noise or disturbance refers to a signal that has the potential to impact the output value of a system. Internally generated disturbance is termed internal disturbance, whereas external disturbance originates from outside the system. Such noise inevitably leads to a deviation in the output value from the desired outcome. Additionally, the term "noise" is employed to describe electrical interference that results in audible noise within a system [15].

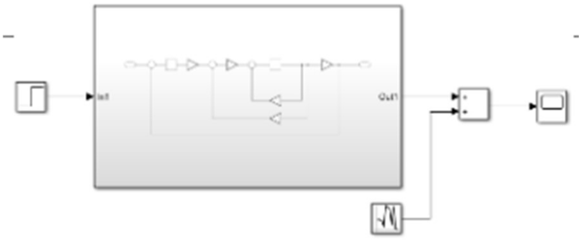


Figure 2.5 Simulink Matlab Noise 1

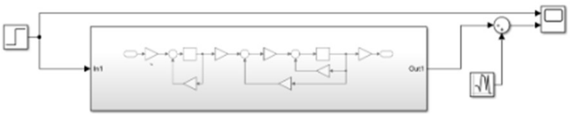


Figure 2.6 Simulink Matlab Noise 2

3. RESULTS AND DISCUSSION

3.1. Simulation Results of LQR (Linear Quadratic Regulator) in the Absence of Noise

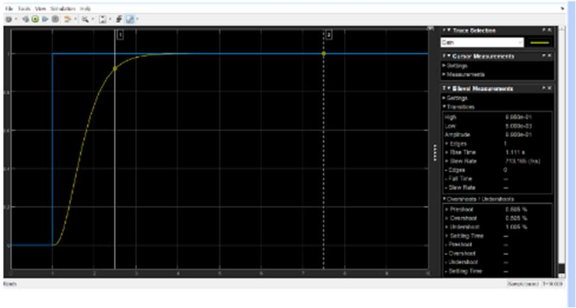


Figure 3. 1 LQR Simulation Results with No Noise

According to the findings depicted in Figure 3.1, the amplitude value from LQR without noise is 0.99, accompanied by a maximum rise time of 1.111s. Additionally, the overshoot and undershoot values are notably minimal, with an overshoot of 0.505% and an undershoot of 1.005%.

3.2 Simulation Results of LQR (Linear Quadratic Regulator) in the Presence of Noise

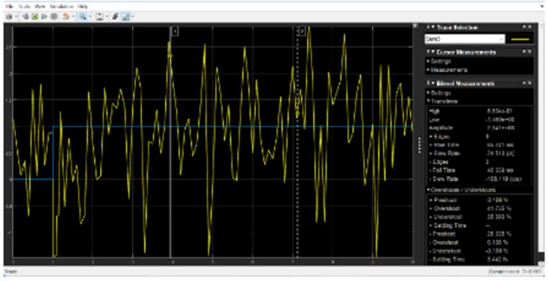


Figure 3.2 LQR Simulation Results in the Presence of Noise

According to the outcomes illustrated in Figure 3.2, noise introduces disruptions to the system's output. The amplitude value from LQR with noise is 2.34, accompanied by a rise time of 85.741s. Notably, the overshoot and undershoot values are considerably elevated, measuring 41.735% for overshoot and 35.093% for undershoot.

3.3 Simulation Results of LQT (Linear Quadratic Tracking) in the Absence of Noise

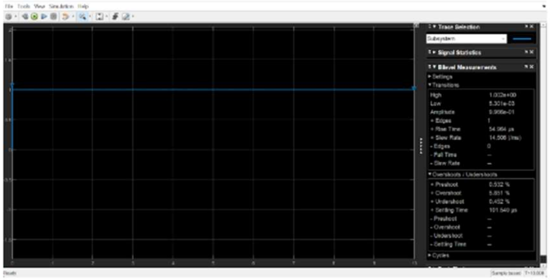


Figure 3.3 LQT Simulation Results with No Noise

As depicted in Figure 3.3, the amplitude value derived from LQT without noise is 0.99, accompanied by a rise time of 54.964µs. Additionally, the overshoot and undershoot values are modest, with an overshoot of 5.851% and an undershoot of 0.452%.

3.4 Simulation Results of LQT (Linear Quadratic Tracking) in the Presence of Noise (3.4)

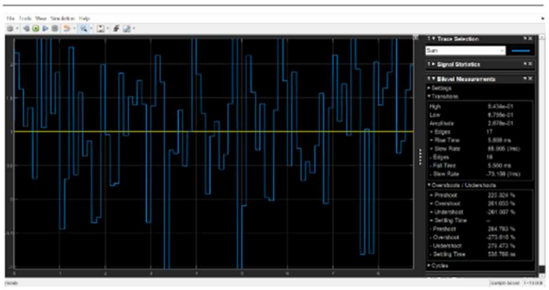


Figure 3.4 LQT Simulation Results in the Presence of Noise

According to the outcomes illustrated in Figure 3.4, noise introduces disruptions to the system's output in the context of LQT. The amplitude value from LQT with noise is 0.2678, with a rise time of 5.888ms. Significantly, the overshoot and undershoot values are notably elevated, measuring 261.033% for overshoot and -261.007% for undershoot.

3.5 Comparing the Output of LQR and LQT

Table 3.1 Comparing Output LQR and LQT

No	LQR	LQT
Amplitudo	0,99	0,99
Overshut	0,505%	5,851%
Undershut	1,005%	0,452%
Rise Time	1,111s	54,964µs.

According to the findings presented in Table 3.1, derived from a comparative analysis of experiments using LQR and LQT, it is observed that the amplitudes in both LQR and LQT are identical. However, the overshoot in LQT surpasses that of LQR. Conversely, the undershoot in LQR is greater than that in LQT.

Table 3.2 LQR and LQT experiments in the presence of noise

No	LQR	LQT
Amplitudo	2,34	0,2678
Overshut	41,735%	261,033%
Undershut	35,093%	-261,007%
Rise Time	85,741s	5,888ms

Examining the findings in Table 3.2, garnered through a comparison of LQR and LQT experiments in the presence of noise, it is evident that the output values deviate significantly from the desired ones when noise is introduced. The inclusion of noise in the circuit leads to notable changes in the output values, characterized by high overshoot and undershoot values, resulting in an irregular graph. Comparing the two methods and considering the added noise, it is apparent that the overshoot value in LQT is exceptionally high and distinctly different from the overshoot produced by LQR.

4. CONCLUSION

The simulations conducted have yielded favorable outcomes for the application of the LQR method to DC motors. The results generated by the LQR method align well with the desired set point and exhibit smaller overshoot compared to LQT. However, in circuits where noise is introduced, there is a significant impact on the resulting output, leading to elevated overshoot values across all circuits. To mitigate the influence of noise in a system, an additional method or filter is essential to reduce noise and enhance the optimality of the resulting output.

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