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Neural Networks Application for the Data of LQG Regulator for the Flexible Joint Robot

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Abstract

This paper describes the investigation of a flexible robotic arm with Degree of Freedom (DOF) through Linear Quadratic Gaussian (LQG) regulator under the influence of noise signals with using diagrams below. The derived model is based on the Euler-Lagrange approach while LQG mode is proposed as a modern control method. A flexible robotic arm that is test in the modern regulator is essential for applications. This is even more interesting while these arms have joints that work independently of each other, but they still ensure a tight connection between the joints. Testing the stability characteristics of the system through this regulator helps readers determine the output signals of a system exactly. From here, the author came up with strategies the match the requirements. Although the initial stage of the operating cycle is not stable with the use of LQG regulator, most of later stages of this process of closed systems of robotic systems gradually become stable. In particular, adjusting LQG for flexible joint robot gives satisfactory simulation results. This promises a positive result of other joint robot. Neural networks applied in this paper have proven its effectiveness in information security issues. It is also very useful for tight control of possible situations such as a large scale attack on network systems, automated control systems. The main contributions of this paper have been clearly demonstrated through two strategies that need to be addressed: LQG, neural networks for the data of LQG regulator.The methods described above have not been previously published for this model. Therefore, this article was born to outline the above objectives and the plans have been satisfactorily implemented. These studies are important because they serve as a necessary database in the selection of control strategies according to the requirements. Simulation results are done by Matlab. The purpose of the study of this paper: the author has searched for a stability of the system through the above methods. The applied method is a thorough study of the structure of the system as well as the construction of algorithms to form the regulator. The result ia a reliable simulation of events after the system is controlled by these regulators.

Keywords: flexible joint, LQG, joint robot, arm robot, neural networks.

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1. Introduction

Today, achievements in the field of technology happen very quickly. The same goes for the automation industry. Research works on robots have been achieved encouraging results. Advances in this area have included applications in the manufacturing industry, mining industries that take advantage of machine labor to replace human labor, and so on. The application of these methods is novel in the control of robotic systems which helps humans to be more proactive in handling possible situations, and at the same time this enables humans to handle systems in a more flexible, modern way. Robots were studied very early [1], which led to the fact that other industries related to robots were also properly invested. Other areas that are related to automation include electronics [2], the control of simple systems and complex systems [3], modeling systems [4] using algorithms, followed by simulation results [5], devices that measure signals from the brain [6], measurement results that reflect the cognitive status of an object [7]. This increases the applications such as the application of emotions to new generation robots [8]. Currently, the application in the medical field of robotics is very diverse [9] from diagnosis to surgical work for patients, the perception of a robot through its contact with an entity [10, 11]. In addition, robots can take on some tasks in nuclear power plants [12], the investigation of the phenomenon of intelligent devices [13-15]. The development of smart devices [16, 17], heavy industry and light industry [18] and applications of underwater robots [19], tracking of aerial targets [20,21], tethered robots [22] or the construction of robots that are capable of parachuting. The application in physical therapy with the help of robots is new [23], robotic wheelchairs can assist the movement of patients [24, 25], the construction of control algorithms in the field of anesthesia [26] and the flexible movement of patients through smart devices [27]. Other subsystems include soft links [28] such as computers, and robotic legs [29] such as legs that are capable of gripping surfaces underwater. Wheels capable of propulsion on the surface of planets are based on [30-33] or a combination of alignment components [34]. New strategies [35] for the above links such as robot self-navigation. These structures, for a linear system [36, 37] or a non-linear system [38, 39] are interested by the author. The weight consideration of a product is always taken into account for smart devices [40] depending on the purpose of the customer. This paper focuses on investigating the stability of the system with LQG regulator under the influence of noise signals. Kalman filter in this case has contributed to solving unwanted signals at the input of the system. Limitations of this method: its security is relatively poor and it can not yet emulate structures of other logic gates. It is not yet able to follow other targets. Therefore, more modern methods need to be designed to ensure above objectives. Neural Networks have been included in this system to solve above shortcomings. The combination of two control methods above has created many outstanding advantages as described above, at the same time they have reduced residual defects with using only one control method. Something that has not been noted in previous articles in this case. Positive simulation results in this paper have been described in the most detail. The structure of this system includes a control device to regulate the operation of a rigid arm. The top of the arms are padded with springs that allow the arms to move flexibly around a defined position. Figure 1 depicts this system in action. It was developed by Quanser [41]. Its other variants have also been developed in this company. In the early stages of the movement, rotational platform can perform its functions, after which the springs can help to fix the position of the arms before the movement of rotational platform. Adaptive control methods in [42, 43, 44] are well suited for flexible robot models. The applicability of these methods to robot modeling is high and obtained results are positive. Neural networks are applied to most of problems of cybernetics [45]. Methods in [46] can be applied to flexible robotic arms to diversify the human-robot approach. Flexible control methods in [47, 48] have been considered for application in nonlinear, switched systems with structures of Euler-Lagrange dynamics. To solve the problem of noise signals, the author has conducted research to add noise filters for these systems. Physics [49], electricity [50], hydrology [51], particles [52], mathematics [53] also applied neural network algorithm as an interesting method. The complexity of the proposed approach in this paper to training neural networks is the need to have preformed data, and these values must be within the allowable range of the training. The network is trained through Matlab commands, which are specified in a command structure of this software. There are many neural network-based control methods that will be introduced in other papers in the future. Building new algorithms in network training is not a small challenge because the work of programming neural networks must be compiled according to a pre-ordered order. Accordingly, the structures have been previously designed by algorithms or by schematic diagrams. These structures can be represented with using Matlab's simulation commands. The computational complexity becomes more complicated when the structure of the algorithm is more complex, that is, the algorithm structure has many branches or it has many loops, it has many sub-algorithms, for example. At that time, the network training programming job is compiled according to the algorithm structure by executing many statements for loops, sub-algorithms for each algorithm. Specifically in the case of this paper, the simulation instructions of the network training were pre-planned in planning the data from the simulation results of PID controller. The instructions executed in training the network in this paper were utilized for the input signals. These input signals are the simulation data of PID controller for this robot model. This is a new job that has never been published before. Therefore, there are no data to compare the effectiveness of this method with previous non-neural control methods. Previous papers for neural network training of a particular robot model are not available but they are simply theories for pure neural network types for any input signals, at the same time they have been simulated by software for specific types of pure neural networks. What is the motive of this study? This research is useful for inspiring further in-depth LQG studies with very interesting operational functions. Modern devices like this model, for example, need to be equipped with a fresh theory of machine learning and LQG to increase awareness for readers. Besides, the source of knowledge will become richer with the appearance of modern control methods. What's so special about the combination of these methods? The answer will become clearer in the following sections of this article. The next section includes the following sections of the paper: The title of Part 2 is ‘Modelling of flexible joint robot’, the title of Part 3 is ‘Simulation results and discussions’. The final part of this paper is ‘conclusion’.

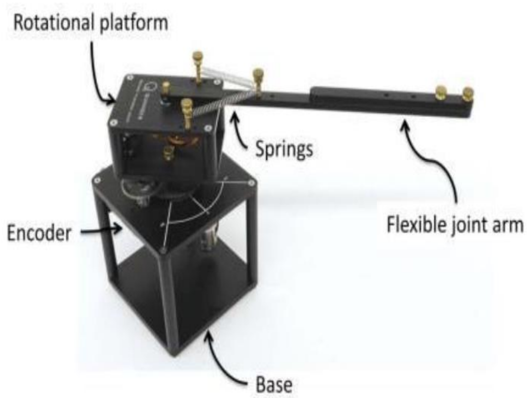

Figure 1. Flexible joint robot arm by Quanser [41]

2. Modelling of flexible joint robot

The arm used in this model is a rotary joint limited by an angle of about 90 degrees and has two Degree Of Freedom (DOF). The base is combined with a set of springs that help balance the movements of the joints. This type of arm is a premise for research for the development of other types of arms. So it is very useful for automation industry. Figure 2 depicts the arm in action on a plane with its base. The Euler-Lagrange equation of motion is applied to this system to obtain the mathematical models of the arm described below. In the paper, the theoretical part and the simulation part of LQG regulator are carried out at the same time. This approach is effective for most robotic systems as well as flexible link systems. So, it is very useful for the above model. In addition, the adjustment of parameters to suit requirements is also relatively simple compared to other methods. Parameters of this system are used to create the model shown in Table 1. Coordinates contained in the platform according to the model [41] are described as follows: the movement of the rotating platform forms an angular (θ) between a vertical axis determined from the beginning, another angular (α) is formed due to the displacement of the flexible joints. This is detailed in Figure 2. The Euler-Lagrange's equation (3) 'L' requires the total kinetic and potential energies. The total potential energy 'P_{Total}' is the sum of the spring's stored energy at the joint and gravity given by (1). The sum of kinetic energies of rotational platform and flexible link manipulator constitutes 'K_{Total}', which is given by (2).

$$P_{Total} = \frac{1}{2} K_s \alpha^2 + mgh\cos(\theta + \alpha) \tag{1}$$

$$K_{Total} = \frac{1}{2} J_h (\dot{\theta}_2) + \frac{1}{2} J_l (\dot{\theta} + \dot{\alpha})^2 \tag{2}$$

$$L = K_{Total} + P_{Total} \tag{3}$$

The Euler-Lagrange equation of motion (4) is used to get the mathematical equations for the rotational acceleration of rotational platform and flexible joint are given by (5) and (6) to form the corresponding motion mechanisms. In (4) the torque is represented by 'τ' and 'q_i' is the variable of differentiation i.e. 'θ' or 'α'. Schematic diagram of flexible joint robotic arm (Fig. 2) is shown below.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial \dot{q}_i} = \tau \tag{4}$$

$$\ddot{\theta} = \frac{1}{J_h}(\tau + K_s \alpha) \tag{5}$$

$$\ddot{\alpha} = -K_s \alpha \left(\frac{1}{J_h} + \frac{1}{J_l}\right) + \frac{1}{J_l} mgh\sin(\theta + \alpha) - \tau \tag{6}$$

$$\begin{cases} \ddot{\theta} = \frac{1}{J_h}(\tau + K_s \alpha) \\ \ddot{\alpha} = -K_s \alpha \left(\frac{1}{J_h} + \frac{1}{J_l}\right) + \frac{1}{J_l} mgh\sin(\theta + \alpha) - \tau \end{cases} \tag{7}$$

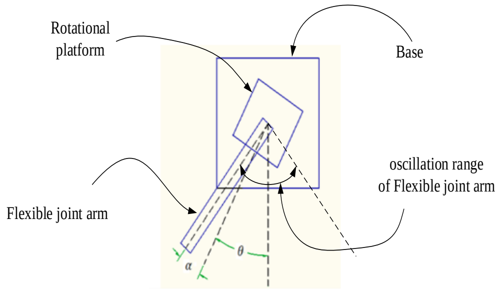

Figure 2. Schematic diagram of flexible joint robotic arm.

Table 1. Parameters of flexible joint robot

Symbol	Description	Value	Units
K_s	Spring stiffness	5.468	N/m
m	Link mass	0.1	kg
J_h	Inertia of rotaltional platform	0.00035	Kgm^2
J_l	Inertia of flexible manipulator	0.003882	Kgm^2
h	Distance of center of gravity of rotational platform	0.06	m
g	Gravitational acceleration	-9.81	N/m
τ	Torque applied to Active joint	0.0134	N-m/A

The author had set state and output variables for the system as follows:

$$\begin{cases} x_1 = \theta, x_2 = \alpha, x_3 = \dot{\theta}, x_4 = \dot{\alpha}, x_5 = \arcsin z \\ y_1 = x_1, y_2 = x_2 \end{cases} \tag{8}$$

The author combined (7) and (8) to obtain the system of state equations describing the system:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 0\\ 0 & \dfrac{K_s}{J_h} & 0 & 0 & 0\\ 0 & -K_s\left(\dfrac{1}{J_h}+\dfrac{1}{J_L}\right) & 0 & 0 & \dfrac{1}{J_L}mgh(\arcsin z)\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \dfrac{\tau}{J_h}\\ -\tau\\ 0\end{bmatrix} \quad (9)$$

Substituting values from table 1 into (8), (9) is shown: z=0.866 has been selected:

$$\begin{cases}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 0\\ 0 & 15622.85 & 0 & 0 & 0\\ 0 & -17031.4 & 0 & 0 & -2.39\times10^{-4}\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 38.28\\ -0.0134\\ 0\end{bmatrix}\\ \begin{bmatrix}y_1\\ y_2\end{bmatrix}=\begin{bmatrix}1 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}\end{cases} \quad (10)$$

The transfer function of the system:

$$G(s)=\frac{38.28s^2-2.167\times10^{-13}s+6.518\times10^5}{s^4+1.703\times10^4 s^2} \quad (11)$$

3. Simulation results and discussions

Procedures for carrying out this research work:

Step 1: Set up the model

Step 2: mathematically represent this model in terms of a function or a transfer function

Step 3: build an algorithm (LQG)

Step 4: simulate the built-in algorithms according to the function of the model

Step 5: Identify and evaluate this program (LQG).

Step 6: the author has applied the data obtained in Step 4 so that the author can conduct simulations according to ANN

Step 7: the author commented on the results obtained in Step 6 (LQG + ANN). Simulation results are shown Figures 4, 5, 6, 7, 8, 9.

Part 1: Model with using LQG regulator.

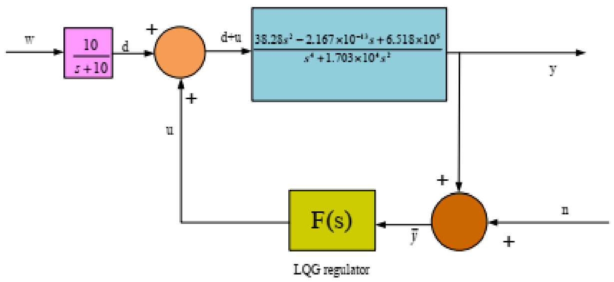

Figure 3. LQG regulator

Figure 3. the value of 'd' is a color noise signal with a spectral density of less than 10 rad/s, the value of 'n' is a white noise signal $E(n^2)=0.01$. The quality indicator 'J':

$$J(u)=\int_0^\infty\left(10y^2+u^2\right)dt$$

The model of the object $\dot{x}=Ax+Bu+Bd,\ \bar{y}=Cx+n$

The calculation process of the program is carried out as shown in Figure 2

Step 1: The author has set up the model as shown in Figure 3

Step 2: The author has programmed on Matlab software (M-file) according to the diagram in Figure 3.

Step 3: The author has pressed "play" on the control bar (M-file) to produce the results as shown below.

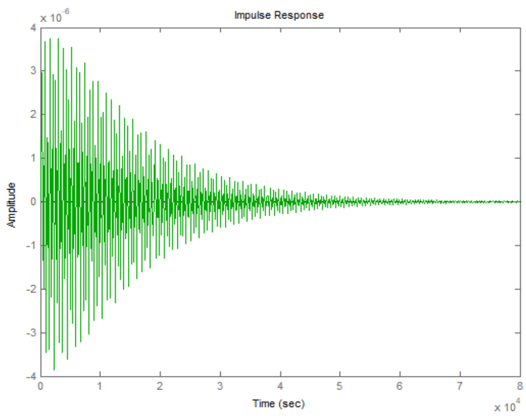

Figure 4. impulse response for the closed form

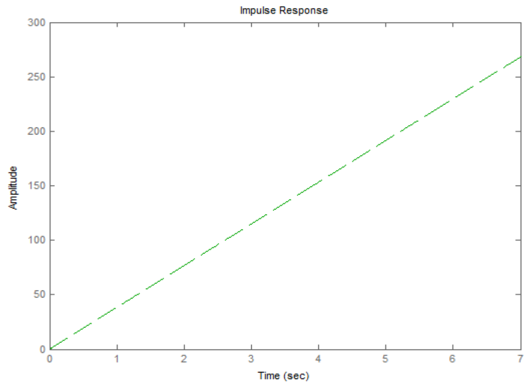

Figure 5. Impulse Response for the Open Form

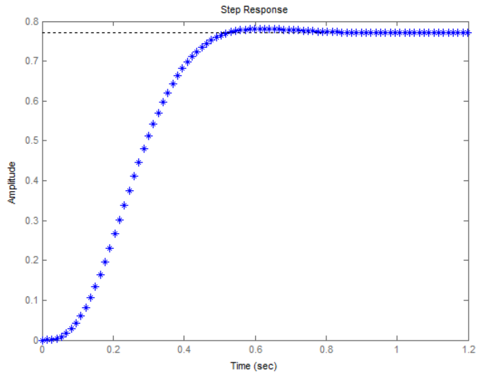

Figure 6. Step Response for the Closed Form

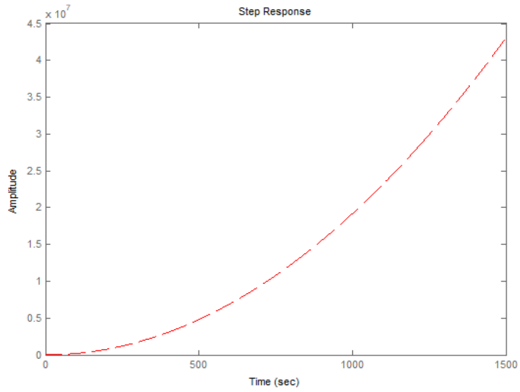

Figure 7. Step Response for the Open Form

Figure 4 impulse response for the closed form (the signal is highlighted in green) is better than the open form (the signal is highlighted in green in Figure 5. In the early stage the fluctuation of this signal is not stable and it fluctuates around the position at zero. The value of the amplitude of the closed form in this case is zero at the latter half of the operating cycle ($5*10^4$s) and the closed form reaches a steady state. For LQG regulator, the closed form responds well. The value of the amplitude of the open form in this case is large and the open form does not reach a steady state.

The value of the green signal in Figure 10 did not reach a certain threshold during the operation of the system. Figure 6 step response for the closed form (the signal is highlighted in blue) is better than that for the open form (the signal is highlighted in red in Figure 7). In the first stage of this cycle, the oscillation value of this blue signal continuously increases. After that, it gradually stabilizes. The value of the amplitude of the closed form in this case is 0.8 and the closed form reaches a steady state. For LQG regulator, the closed form responds well. Meanwhile, the open form can not respond well. In general, for LQG regulator, the system responds well for the closed form. The value of the red signal in Figure 7 did not reach a certain threshold during the operation of the system.

Figure 4 and Figure 6: this results are satisfied with the requirements set because the final values of these results are determined by a specific number.

Part 2: Model with using Neural Networks Application for the data of LQG regulator

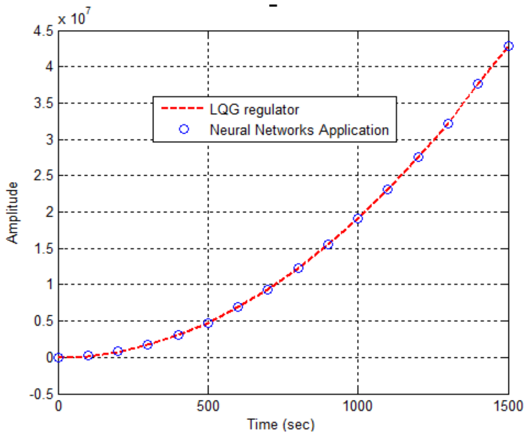

Figure 8. Step Response of the Open Form ‘G(S)’

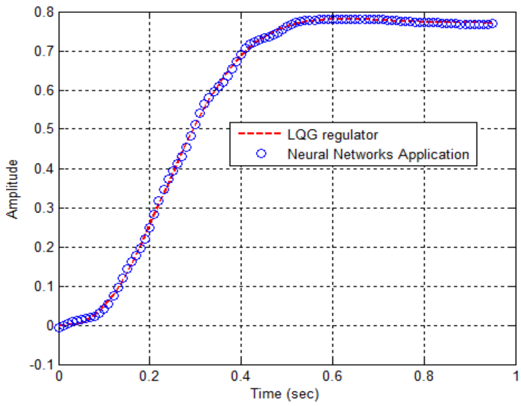

Figure 9. Step Response of the Closed Form ‘G(S)’

Figures 8, 9 show that Neural Networks Application is the best choice for training the network according to a given control method. Results show that values of control methods are relatively consistent with each other and results have achieved desired requirements.

After examining Figures 8 and 9, the signals denoted by the circle have 'followed' the signals denoted by the red dashed line. This shows that the neural network training is working well for all cases including the closed or open form of the design. The more the neural network's signals 'stick' to the target, the more satisfying the results achieved. In this case, they worked as planned

Limitations of this study: studies related to the topic are scarce so the author can refer to them. Recommendation: the author needs the cooperation of experts to have more rich content on this issue. The work of the future includes the development of artificial algorithms at a richer level of genre.

4. Conclusion

LQG regulator in case of noise signals affecting this system has been proposed by the author. Simulation results have been accepted for positive results. This allows the closed form to reach steady state in a long time. In fact, there are many noise signals affecting the system due to the working environment of the system. This can affect the output quality of a plan. In the future, LQG regulator can be implemented on complex systems to address advantages as the author described above. ANN + LQG is very useful in ensuring the security of the system from the approach owner of a system to the role of proxy. This method can be applied to flexible links in robotic arm systems, robotic biomedical systems in the future.

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