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Control issues, artificial neural network (ANN) for acrobot system

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Abstract

Acrobot is a robotic system with several levels of operational states investigated by the author. Due to the limited nature of the investigation under certain ideal conditions, designers have to create some algorithms that control the system most appropriately in a given working environment. In this paper, the author proposed the problem of designing, modeling and controlling an acrobot system, including ANN. Mathematical models, Simulink are also presented in a specific way. Simulation parameters have been adjusted to be the most suitable and intuitive. Based on the simulation data, the performance analysis of the system becomes more accurate. Above suggestions are intended to serve vocational education and scientific research. ANN is the most intelligent control method currently added in this paper to firmly confirm its effectiveness in all problems. Proposing control strategies for different models is also applied by the author.

Keywords: acrobot, PID strategy, LEAD strategy, LAG strategy, ANN, simulation.

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1. Introduction

Nowadays, control algorithms including PID, Sliding mode, and Fuzzy mode applied to electric motors have yielded encouraging results. Above methods are a key component in controlling a flexible robotic arm. Stability control algorithms have also been implemented in the labs for robotic arms, and they can eventually appear in factories for production. Intelligent robots are controlled by a combination of genetic algorithms [1], classical algorithms to intelligent algorithms [2]. These algorithms can be applied to a small branch of a robotic arm. Research on these control algorithms brings many practical applications such as: self-driving spacecraft, unmanned submarine robot. In this paper, the author proposed several control methods to control the stability of a plan. This plan namely an ac-robot system. These control methods are viewed as a direct application to a system. The application of another intelligent control methods for any robot arm whose electric motor is in joints of the robot arm can be applied the following control methods. Ac-robot systems as well as other systems that are structurally similar to Inverted Pendulum, Pendubot [3] and Reaction wheel inverted pendulum [4], which are nonlinear systems such as Single Input Multi Output (SIMO). They are nonlinear systems. Therefore, the design of controllers for these systems always faces challenges with many signals at the output. The output signals are valid only when positions near the working point are considered in this paper. This system is described by 2 metal bars that have a joint between 2 metal bars. The first metal bar is denoted 'link 1' and the 2nd metal bar is denoted 'link 2'. This coupling is driven by a motor. This joint is a flexible joint. The top of ‘link 1’ is attached to the passive joint and ‘link 1’ is moved freely around this passive joint. Ac-robot system is described by a link between ‘link 1’ and ‘link 2’ as shown below (Figure 1).

2. Dynamic equation of model system

Models are all expressed by mathematical equations. Operating states of the system are described by these mathematical equations. Through equations, the author proceeds to establish a model that has the intervention of the controller. The purpose of this is to help the system achieve the desired values. In the future, controllers can be connected to the system via wireless devices. This is useful for maintenance cases where working conditions are harsh for humans. Usually, there are one or more controllers connected to a system by wired devices at the present time. After successfully setting up mathematical equations, the author has processed to calculate the values: the value of the response in regulators, the value of the response in PID controller, ANN. After finding above values, the author found out control signals in the open system and the closed system for the above regulators, PID controller, ANN. Ac-robot or an inverted pendulum can be described by mathematical equations. The two-dimensional coordinate system: Ox and Oy is depicted as shown in Figure 1[5]. Control methods to survey [6, 7, 8] can be applied to the model [4]. Planar pendubot [9] with intelligent control methods is a promising work for the author. Swing-Up Control [10] for Reaction wheel inverted pendulum is a good idea. Chaotic Perturbation [11] can be adjusted with newer and more flexible control methods. Hybrid control [12] with neural network forms a new research direction. Application of ant colony algorithm [13] in optimal control of robotic arm systems is an interesting future work. Energy based control [14] for robotic arms through its movement is an elaborate research program. Hybrid control[15] with navigation functions for pendubot is a great mission. Control methods in [16] are consistent with Pendubot. A positioning control strategy [17] for robotic arms to examine their operation more closely. Balance control for an acrobot[18] in various forms is a great concern of the author. Inverse linear quadratic method [19] can be used for Pendubot.

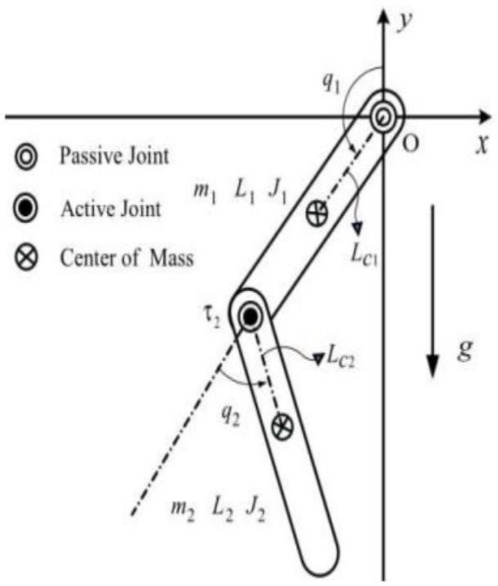

Figure 1. Mathematical model of Acrobot System.

Parameters of Acrobot System in Table 1. Variables are: q_1, q_2, τ_2. Where q_1 and q_2 are output signals during τ_2 is input signal. Variables are unknown values. In the process of designing controllers for these systems, readers can better understand the nature of the relationships between input signals and output signals through voltage signals, the torque of an electric motor. In Fig 1, the x-axis of the Cartesian coordinate system was chosen to be the reference level of zero potential energy. Letting $X_i = \left[X_i^x, X_i^y\right] \in R^2$ be the absolute position of the COM of the i[th] link gives [5]:

$$X_1 = \begin{bmatrix} Lc_1 \sin q_1 \\ Lc_1 \cos q_1 \end{bmatrix} \quad (1)$$

$$X_2 = \begin{bmatrix} L_1 \sin q_1 + L_{c2} \sin(q_1 + q_2) \\ L_1 \cos q_1 + L_{c2} \cos(q_1 + q_2) \end{bmatrix} \quad (2)$$

The kinetic energy is $K(q,\dot{q})$, the potential energy is V(q):

$$K(q,\dot{q}) = \frac{1}{2}\sum_{i=1}^{2}\left[m_i X_i^2 + J_1\dot{q}_1^2 + J_2(\dot{q}_1 + \dot{q}_2)^2\right]$$

$$K(q,\dot{q}) = \frac{1}{2}\left[\dot{q}_1 \quad \dot{q}_2\right] M(q_2) \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} \quad (3)$$

Where

$$M(q_2) = \begin{bmatrix} a_1 + a_2 + 2a_3\cos(q_2) & a_2 + a_3\cos(q_2) \\ a_2 + a_3\cos q_2 & a_2 \end{bmatrix} \quad (4)$$

$$\begin{cases} a_1 = m_1 L_{C1}^1 + m_2 L_1^2 + J_1 \\ a_2 = m_2 L_{C2}^2 + J_2 \\ a_3 = m_2 L_1 L_{C2} \\ a_4 = (m_1 L_{c1} + m_2 L_1) g \\ a_5 = m_2 L_{c2} g \end{cases} \quad (5)$$

State space equations is created as:

$$x = \left[x_1 \quad x_2 \quad x_3 \quad x_4\right]^T = \left[q_1 \quad \dot{q}_1 \quad q_2 \quad \dot{q}_2\right]^T \quad (12)$$

Let

$$H(q,\dot{q}) = \left[H_1(q,\dot{q}) \quad H_2(q,\dot{q})\right]^T := C(q,\dot{q})\dot{q} + G(q) \quad (13)$$

Then, the dynamic equation (8) can be described as:

$$\dot{x} = f(x) + g(x)\tau_2 \quad (14)$$

Where

$$\begin{cases} f(x) = \left[x_2 \quad P(1,1) \quad x_4 \quad P(2,1)\right]^T \\ g(x) = \left[0 \quad Z(1,1) \quad 0 \quad Z(2,1)\right]^T \end{cases} \quad (15)$$

Where P(i, j) and Z(i, j) are matrices have the i[th] row and j[th] column of P and Z. Therefore, P and Z are determined as:

$$\begin{cases} P = -M^{-1}(q_2)\begin{bmatrix} H_1(q,\dot{q}) \\ H_2(q,\dot{q}) \end{bmatrix} \\ Z = -M^{-1}(q_2)\begin{bmatrix} 0 \\ 1 \end{bmatrix} \end{cases} \quad (16)$$

Table 1. Parameters of Acrobot System

Parameters	Values
m_1	0.8 kg
L_1	0.18 m
L_{C1}	0.11 m
m_2	0.2 kg
L_2	0.18 m
L_{c2}	0.09 m
J_1	0.0022 Kg.m^2
J_2	0.00054 Kg.m^2

With parameters of model in Table 2:

Table 2. Parameters of model

Parameters and variables	Described
q_1	Angle of Link 1
q_2	Angle of Link 2
$\dot{q}_1$	Angle velocity of Link 1
$\dot{q}_2$	Angle velocity of Link 2
m_1	Mass of Link 1
L_1	Length of Link 1
L_{c1}	Distance from Passive joint to the center of mass of the Link 1
m_2	Mass of Link 2
L_2	Length of Link 2
L_{c2}	Distance from Active joint to the center of mass of the Link 1
J_1	Moment of the Inertia Link 1
J_2	Moment of Inertia Link 2
g	Gravitatinal acceleration
τ_2	Torque applied to Active joint

3. The survey of the system

The state variable equations of the system are described as follows:

$$\begin{cases} \dot{x} = Ax + Bu \\ c = Cx + Du \end{cases} \quad (17)$$

Where

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \frac{\partial f_1}{\partial x_4} & .... & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} & \frac{\partial f_2}{\partial x_4} & ..... & \frac{\partial f_2}{\partial x_n} \\ ..... & ..... & .... & .... & .... & .... \\ \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \frac{\partial f_1}{\partial x_4} & .... & \frac{\partial f_1}{\partial x_n} \end{bmatrix}, B = \begin{bmatrix} \frac{\partial f_1}{\partial u} \\ \frac{\partial f_2}{\partial u} \\ .... \\ \frac{\partial f_n}{\partial u} \end{bmatrix} \quad (18)$$

With above parameters, matric A and B of state space model, $G_1(s)$, $G_2(s)$ are calculated:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 70.6961 & -19.6783 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ -94.9903 & 130.9458 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ -185.7355 \\ 0 \\ 927.3017 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, D = 0.$$

$$G_1(s) = \frac{-185.7}{s^2 + 19.68s - 70.7} \quad (19)$$

$$G_2(s) = \frac{927.3s^2 - 6074s - 4.791\times 10^4}{s^4 + 19.68s^3 - 70.7s^2} \quad (20)$$

$$G_3(s) = \frac{-185.7s}{s^2 + 19.68s - 70.7} \quad (21)$$

$$G_4(s) = \frac{927.3s^2 - 6074s - 4.791\times 10^4}{s^3 + 19.68s^2 - 70.7s} \quad (22)$$

4. Controller design with using PID stragery

PID controllers are commonly used to regulate the time domain behavior of many different types of dynamic plants [20]. The transfer function of PID control is given by:

$$G_{PID} = K_P + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s} = \frac{K_D\left[s^2 + \frac{K_P}{K_D}s + \frac{K_I}{K_D}\right]}{s} \quad (23)$$

5. Controller design with using LEAD and LAG compensators

Lead compensator is a soft approximation of PD controller, the PD controller, given by $G_{PD}(s) = K_P + K_D s$, is not physically implementable, since it is not proper, and it would differentiate high frequency noise, thereby producing large swings in output. To avoid this, PD-controller is approximated to lead controller of the following form:

$$G_{PD}(s) \approx G_{Lead}(s) = K_P + K_D \frac{P_s}{s+P} \quad (24)$$

The large the value of P, the better the lead controller approximates PD control, rearranging gives:

$$G_{Lead}(s) = K_P + K_D \frac{P_s}{s+P} = \frac{K_P(s+P) + K_D P_s}{s+P} \quad (25)$$

$$G_{Lead}(s) = \frac{(K_P + K_D P)s + K_P P}{s+P} \quad (26)$$

$$G_{Lead}(s) = (K_P + K_D P)\frac{s + \left[\frac{K_P P}{K_P + K_D P}\right]}{s+P} \quad (27)$$

Now, let

$$K_C = K_P + K_D P \quad (28)$$

and

$$Z = \left[\frac{K_P P}{K_P + K_D P}\right] \quad (29)$$

The author obtained the following approximated controller transfer function of PD controller, and called lead compensator. If Z<P: this controller is called a lead controller (or lead compensator). If Z>P: this controller is called a lag controller (or lag conpensator) . The transfer function of lead compensator is given by (31). The Lag compensator is a soft approximation of PI controller, it is used to improve the steady state response, particularly, to reduce steady state error of the system, the reduction in the steady state error accomplished by adding equal numbers of poles and zeros to a systems. Since PI controller by it self is unstable, the author approximated the PI controller by introducing value of P_0 that is not zero but near zero, the smaller the author made P_0, the better this controller approximates the PI controller, and the approximation of PI controller will have the form by (33).

$$G(s) = K_C \frac{s+Z}{s+P} \quad (30)$$

$$G_{lead}(s) = K_c \frac{(s+Z_0)}{s+P_0} \quad P > Z \quad (31)$$

$$G_{PI}(s) \approx G_{lag}(s) = K_P + \frac{K_I}{s} = \frac{K_P s + K_I}{s} = K_P \frac{\left(s + \frac{K_I}{K_P}\right)}{s} \quad (32)$$

$$G_{lag}(s) = K_c \frac{(s+Z_0)}{s+P_0} \quad (33)$$

6. Simulation results and dicussions

Diagrams of the system with using PID controller, LEAD compensator, LAG compensator, ANN and simulation results are shown Figures 2, 3, 4, 5, 6, 7, ..., 70.

Part 1: Model with using PID controller

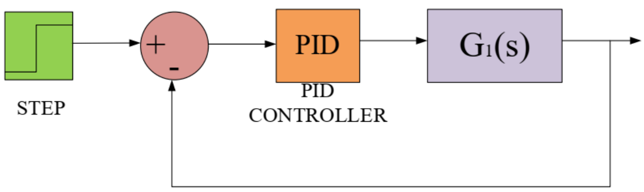

Figure 2. Simulink model of PID controller $G_1(s)$

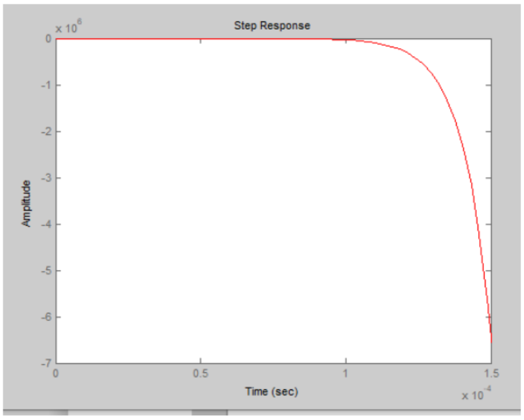

Figure 3. step response of the closed system for PID controller $G_1(s)$

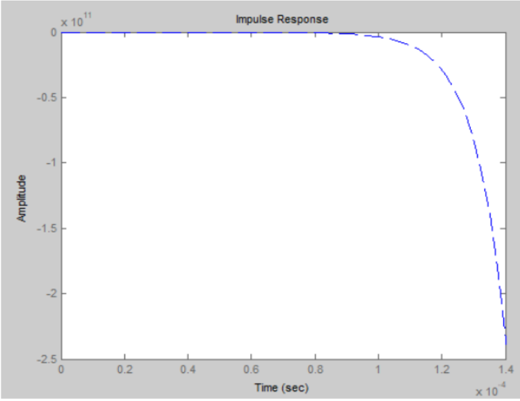

Figure 4. impulse response of the closed system for PID controller $G_1(s)$

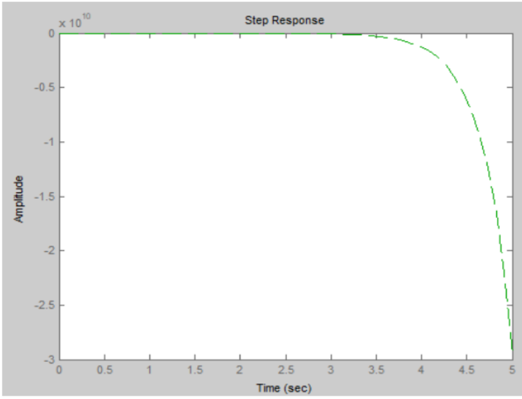

Figure 5. step response of the open system for PID controller $G_1(s)$

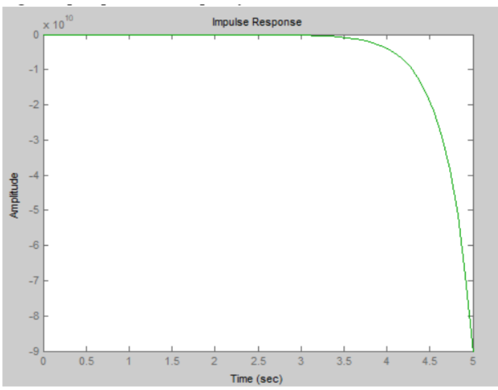

Figure 6. impulse response of the open system for PID controller $G_1(s)$

Figure 4: impulse response for the closed system (the signal is highlighted in blue) is worse than the open system (the signal is highlighted in green in Figure 6). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of PID controller, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 3: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in green in Figure 5). The value of amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type

of PID controller, the closed system does not respond well. Meanwhile, the open system can not respond well.

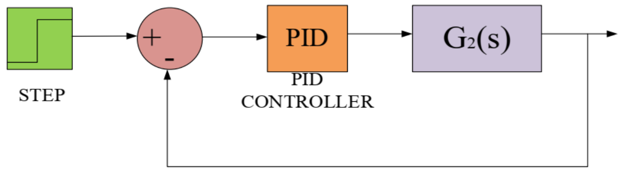

Figure 7. Simulink model of PID controller $G_2(s)$

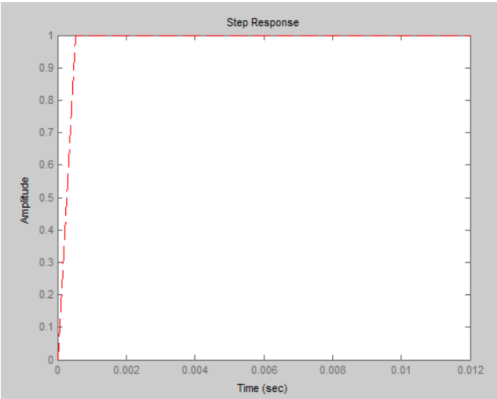

Figure 8. step response of the closed system for PID controller $G_2(s)$

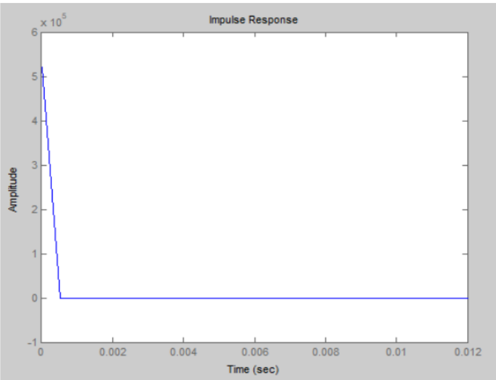

Figure 9. impulse response of the closed system for PID controller $G_2(s)$

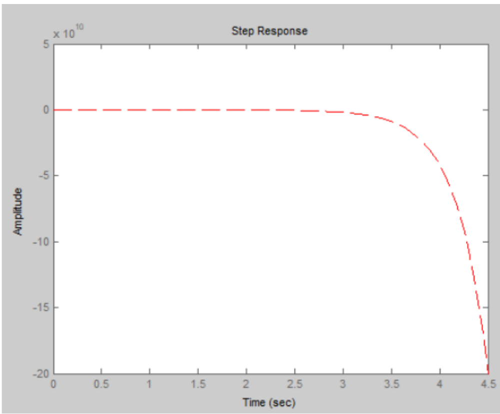

Figure 10. step response of the open system for PID controller $G_2(s)$

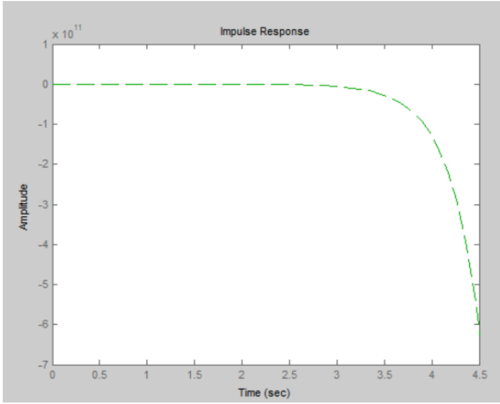

Figure 11. impulse response of the open system for PID controller $G_2(s)$

Figure 9: impulse response for the closed system (the signal is highlighted in blue) is better than the open system (the signal is highlighted in green in Figure 11). The value of the amplitude of the oscillation of the closed system in this case is zero and the closed system reaches a steady state. For this type of PID controller, the closed system responds well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 8: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 10). The value of amplitude of the oscillation of the closed system in this case is 1 and the closed system reaches a steady state. For this type of PID controller, the closed system responds well. Meanwhile, the open system can not respond well.

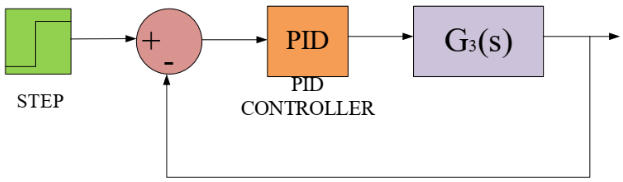

Figure 12. Simulink model of PID controller $G_3(s)$

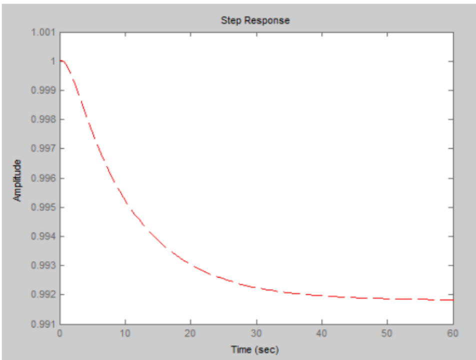

Figure 13. step response of the closed system for PID controller $G_3(s)$

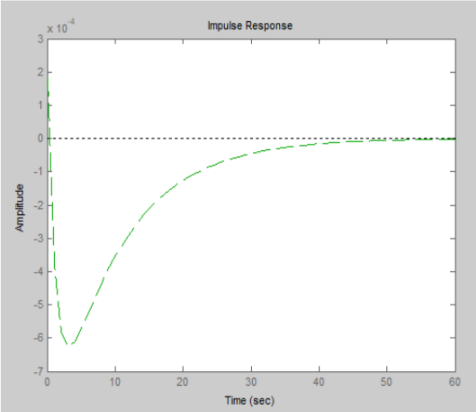

Figure 14. impulse response of the closed system for PID controller $G_3(s)$

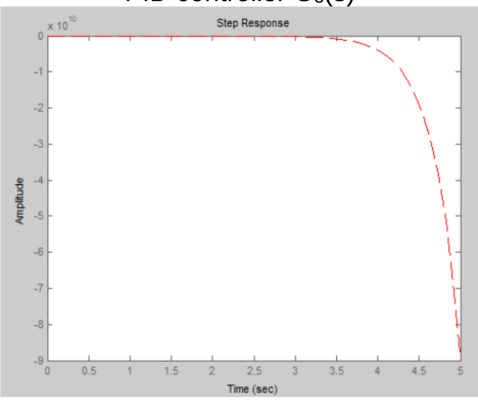

Figure 15. step response of the open system for PID controller $G_3(s)$

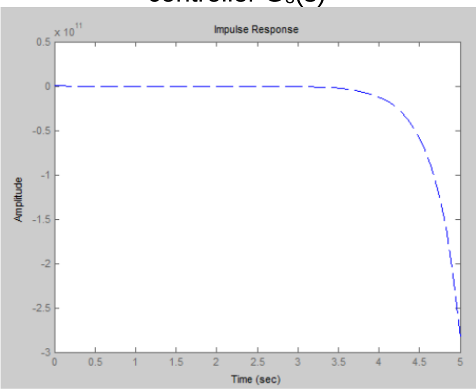

Figure 16. impulse response of the open system for PID controller $G_3(s)$

Figure 14: impulse response for the closed system (the signal is highlighted in green) is better than the open system (the signal is highlighted in blue in Figure 16). The value of the amplitude of the oscillation of the closed system in this case is zero and the closed system reaches a steady state. For this type of PID controller, the closed system responds well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 13: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 15). The value of the amplitude of the oscillation of the closed system in this case is 0.992 and the closed system reaches a steady state. For this type of PID controller, the closed system responds well. Meanwhile, the open system can not respond well.

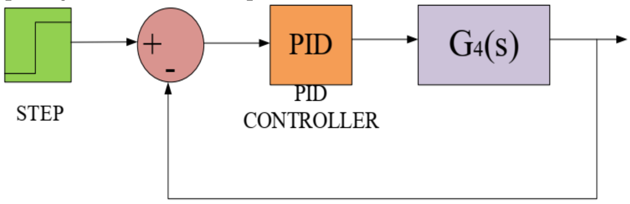

Figure 17. Simulink model of PID controller $G_4(s)$

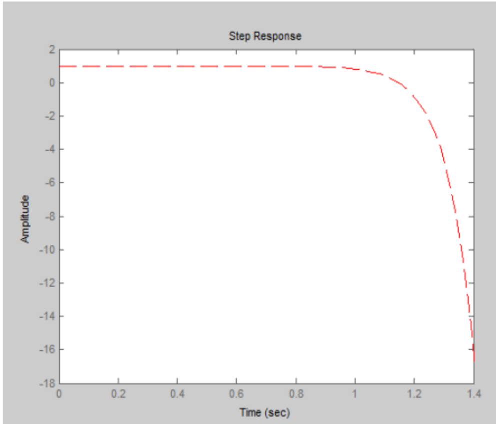

Figure 18. step response of the closed system for PID controller $G_4(s)$

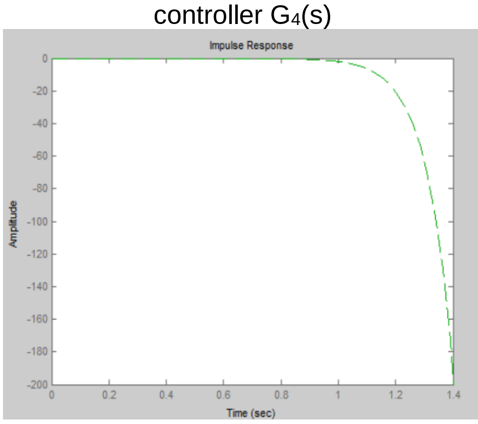

Figure 19. impulse response of the closed system for PID controller $G_4(s)$

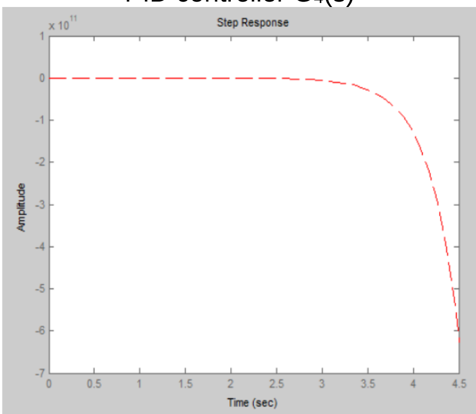

Figure 20. step response of the open system for PID controller $G_4(s)$

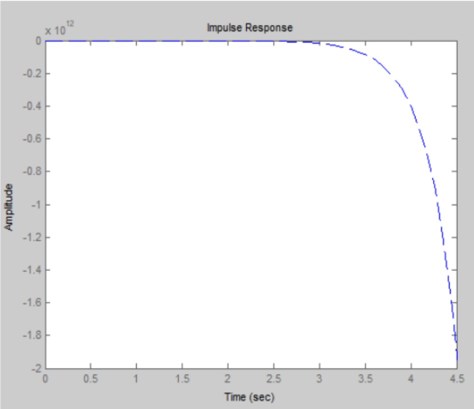

Figure 21. impulse response of the open system for PID controller $G_4(s)$

Figure 19: impulse response for the closed system (the signal is highlighted in green) is better than the open system (the signal is highlighted in blue in Figure 21). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of PID controller, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 18: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 20). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of PID controller, the closed system does not respond well. Meanwhile, the open system can not respond well.

Part 2: Model with using Lead compensator

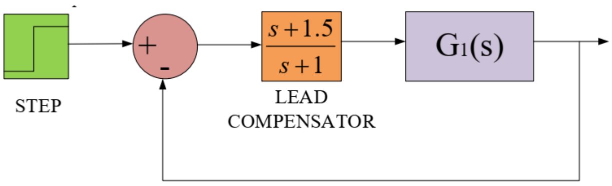

Figure 22. Simulink model of Lead compensators $G_1(s)$

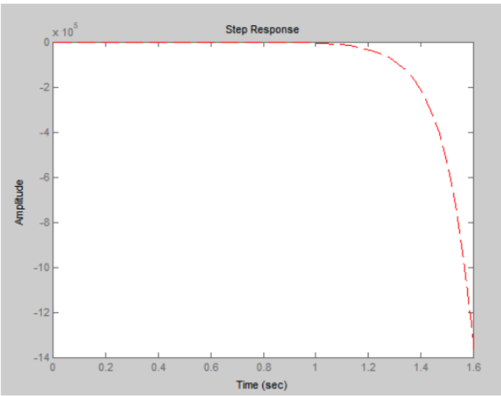

Figure 23. step response of the closed system for LEAD compensator $G_1(s)$

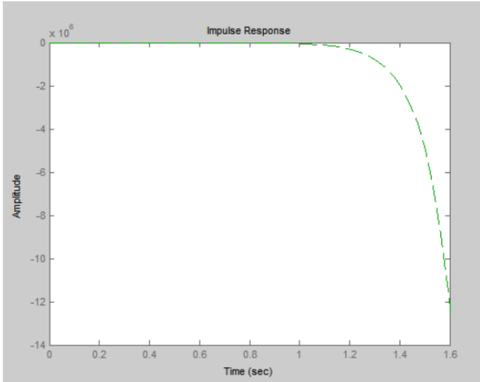

Figure 24. impulse response of the closed system for LEAD compensator $G_1(s)$

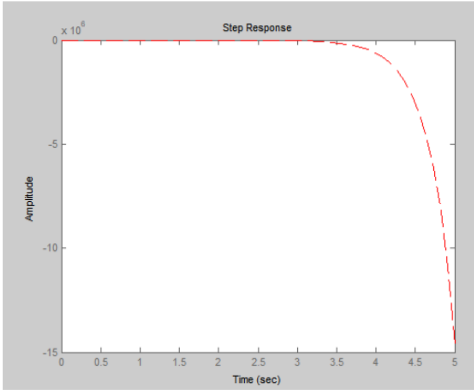

Figure 25. step response of the open system for LEAD compensator $G_1(s)$

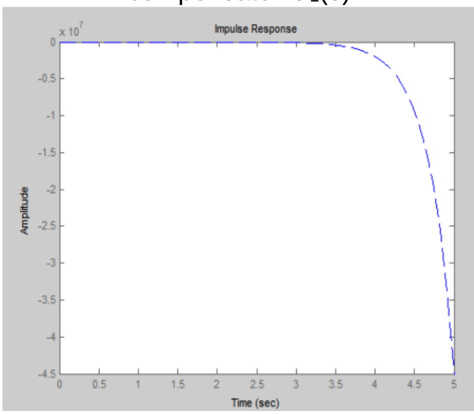

Figure 26. impulse response of the open system for LEAD compensator $G_1(s)$

Figure 24: impulse response for the closed system (the signal is highlighted in green) is better than the open system (the signal is highlighted in blue in Figure 26). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 23: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 25). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this

type of LEAD compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

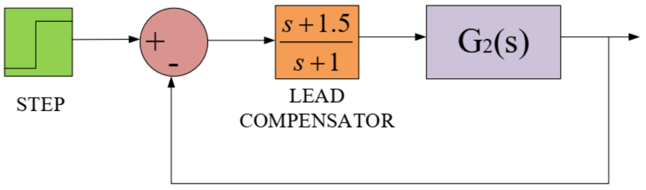

Figure 27. Simulink model of Lead compensators $G_2(s)$

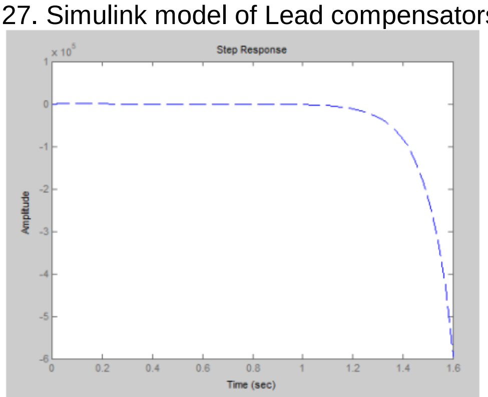

Figure 28. step response of the closed system for LEAD compensator $G_2(s)$

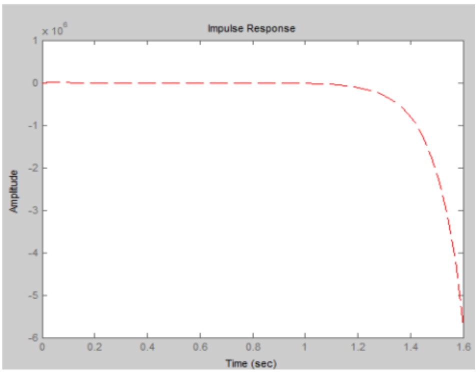

Figure 29. impulse response of the closed system for LEAD compensator $G_2(s)$

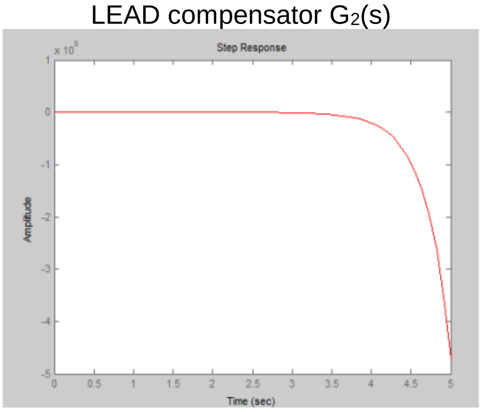

Figure 30. step response of the open system for LEAD compensator $G_2(s)$

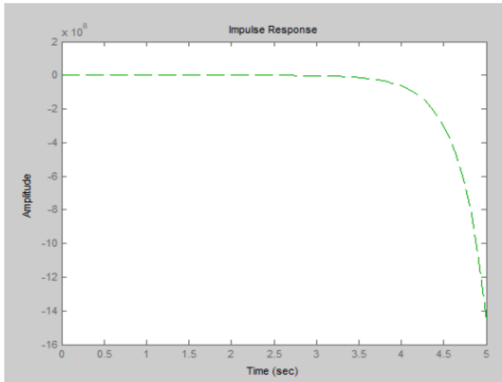

Figure 31. impulse response of the open system for LEAD compensator $G_2(s)$

Figure 29: impulse response for the closed system (the signal is highlighted in red) is better than the open system (the signal is highlighted in green in Figure 31). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 28: step response for the closed system (the signal is highlighted in blue) is better than that for the open system (the signal is highlighted in red in Figure 30). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

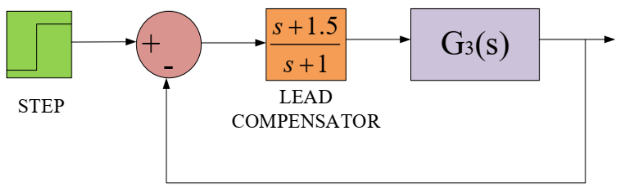

Figure 32. Simulink model of Lead compensators $G_3(s)$

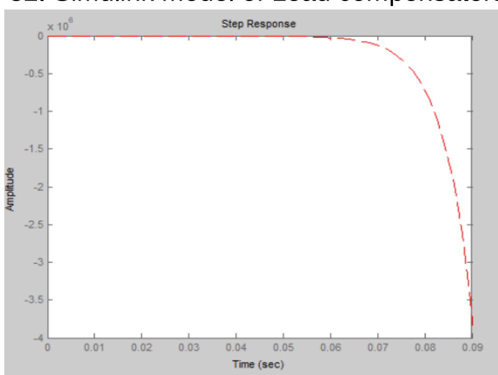

Figure 33. step response of the closed system for LEAD compensator $G_3(s)$

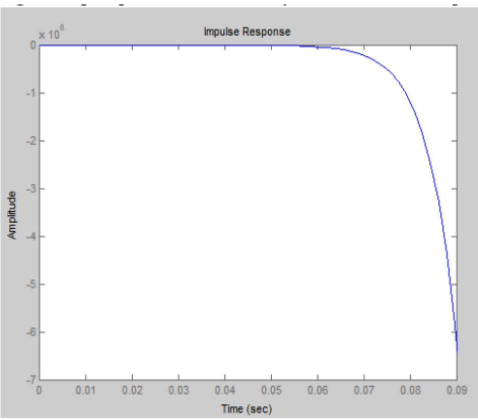

Figure 34. impulse response of the closed system for LEAD compensator G3(s)

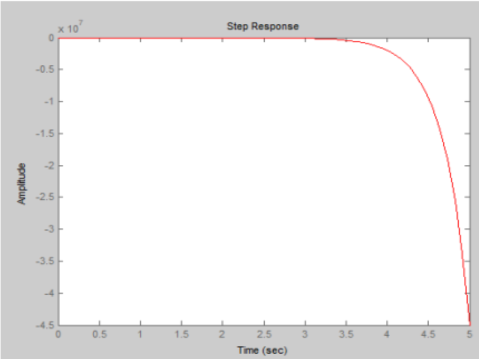

Figure 35. step response of the open system for LEAD compensator G3(s)

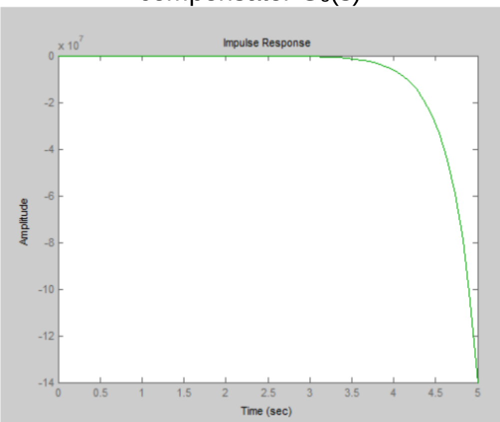

Figure 36. impulse response of the open system for LEAD compensator G3 (s)

Figure 34: impulse response for the closed system (the signal is highlighted in blue) is worse than the open system (the signal is highlighted in green in Figure 36). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 33: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 35). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

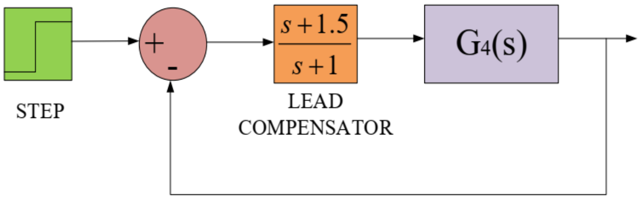

Figure 37. Simulink model of Lead compensators G4(s)

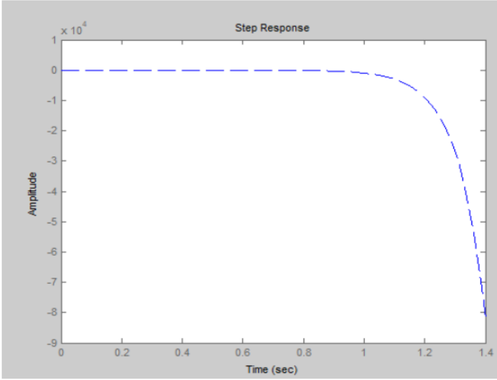

Figure 38. step response of the closed system for LEAD compensator G4(s)

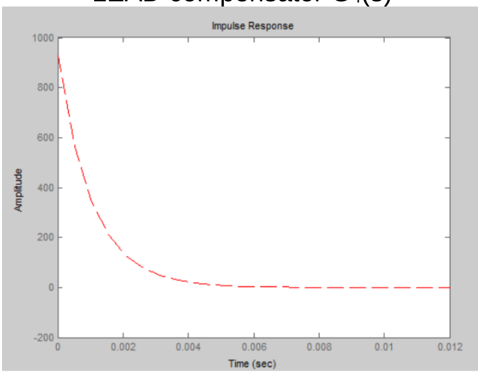

Figure 39. impulse response of the closed system for LEAD compensator G4(s)

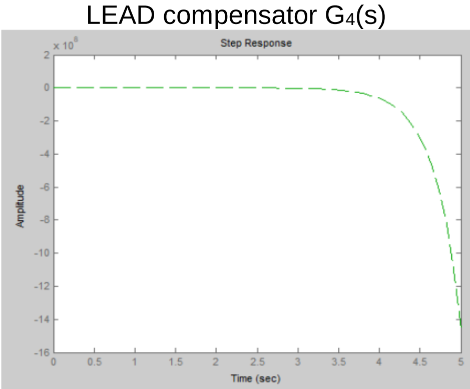

Figure 40. step response of the open system for LEAD compensator G4(s)

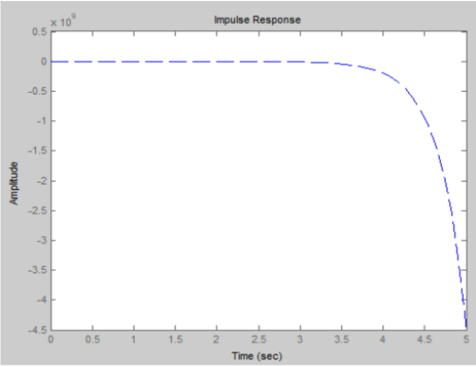

Figure 41. impulse response of the open system for LEAD compensator $G_4(s)$

Figure 39: impulse response for the closed system (the signal is highlighted in red) is better than the open system (the signal is highlighted in blue in Figure 41). The value of the amplitude of the oscillation of the closed system in this case is zero and the closed system reaches a steady state. For this type of LEAD compensator, the closed system responds well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 38: step response for the closed system (the signal is highlighted in blue) is better than that for the open system (the signal is highlighted in green in Figure 40). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LEAD compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

Part 3: Model with using Lag compensator

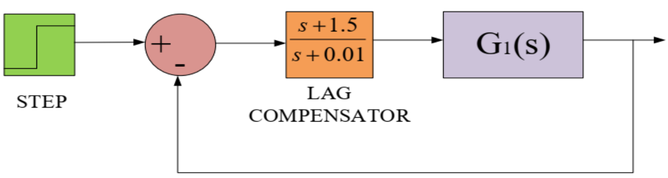

Figure 42. Simulink model of Lag compensators $G_1(s)$

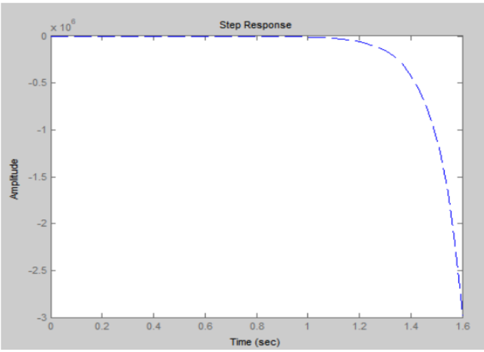

Figure 43. step response of the closed system for LAG compensator $G_1(s)$

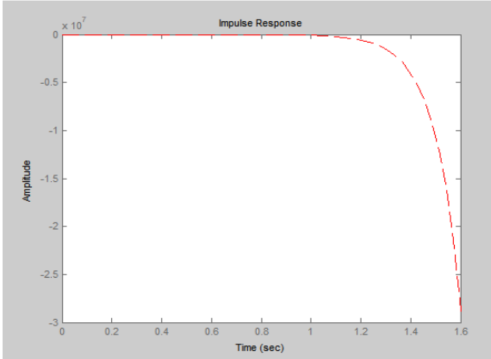

Figure 44. impulse response of the closed system for LAG compensator $G_1(s)$

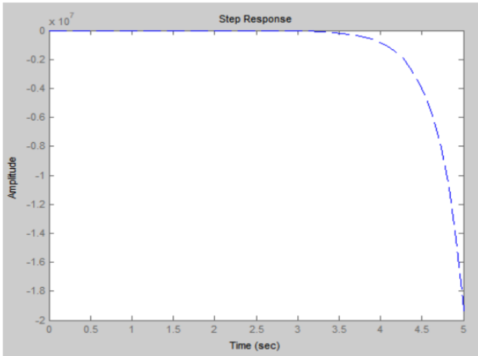

Figure 45. step response of the open system for LAG compensator $G_1(s)$

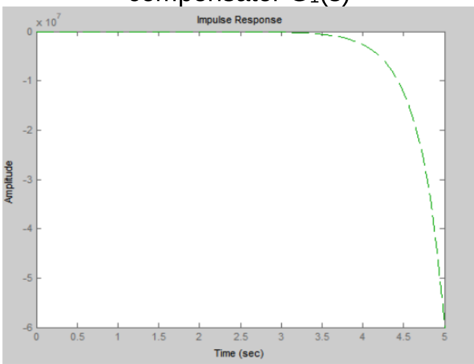

Figure 46. impulse response of the open system for LAG compensator $G_1(s)$

Figure 44: impulse response for the closed system (the signal is highlighted in red) is better than the open system (the signal is highlighted in green in Figure 46). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 43: step response for the closed system (the signal is highlighted in blue) is better than that for the open system (the signal is highlighted in blue in Figure 45). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

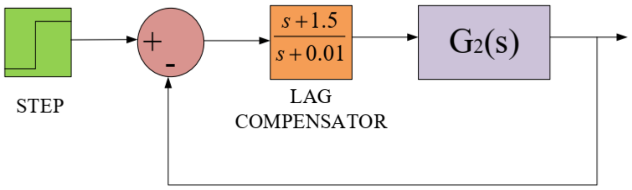

Figure 47. Simulink model of Lag compensators $G_2(s)$

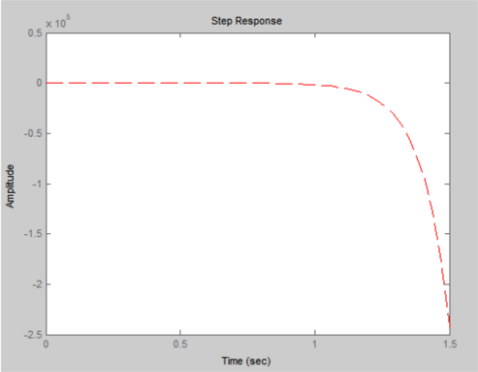

Figure 48. step response of the closed system for LAG compensator $G_2(s)$

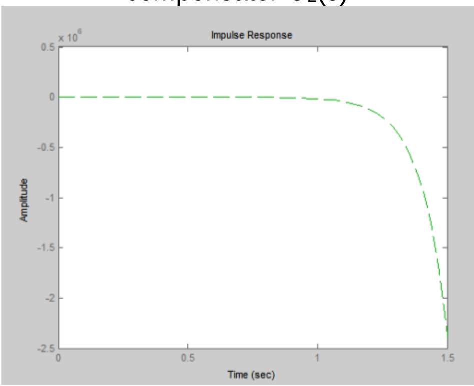

Figure 49. impulse response of the closed system for LAG compensator $G_2(s)$

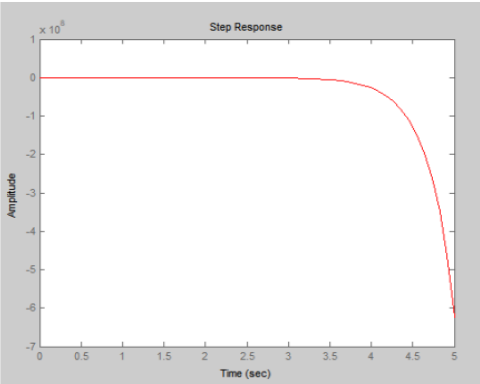

Figure 50. step response of the open system for LAG compensator $G_2(s)$

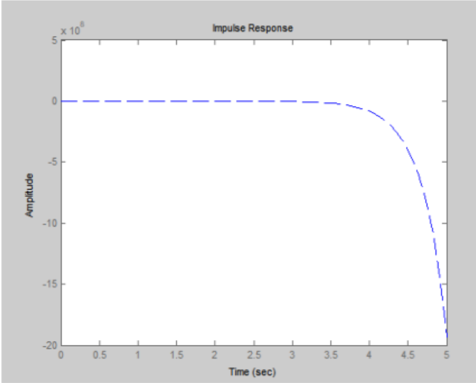

Figure 51. impulse response of the open system for LAG compensator $G_2(s)$

Figure 49: impulse response for the closed system (the signal is highlighted in green) is better than the open system (this signal is highlighted in blue in Figure 51). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 48: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 50). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

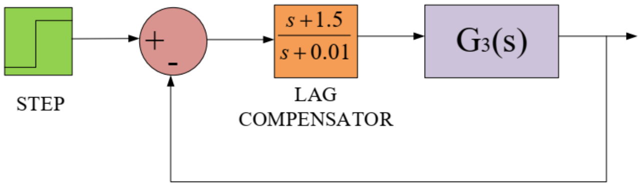

Figure 52. Simulink model of Lag compensators $G_3(s)$

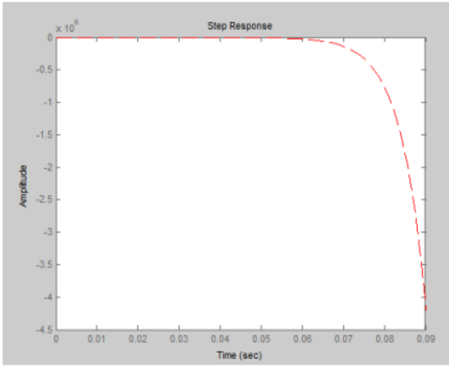

Figure 53. step response of the closed system for LAG compensator $G_3(s)$

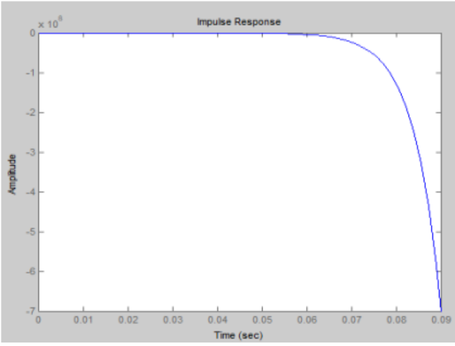

Figure 54. impulse response of the closed system for LAG compensator G3(s)

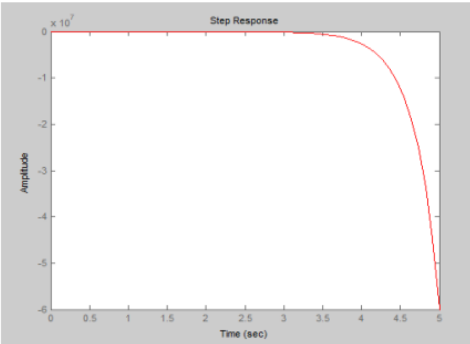

Figure 55. step response of the open system for LAG compensator G3(s)

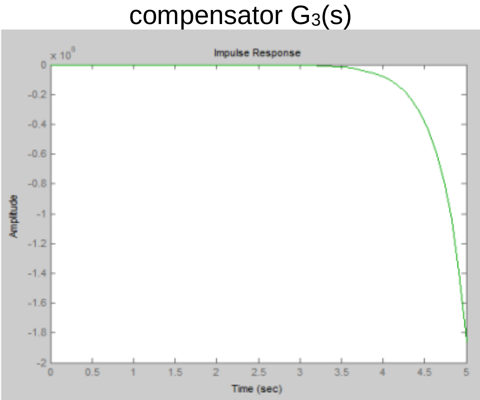

Figure 56. impulse response of the open system for LAG compensator G3(s)

Figure 54: impulse response for the closed system (this signal is highlighted in green) is better than the open system (the signal is highlighted in blue in Figure 56). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 53: step response for the closed system (the signal is highlighted in red) is better than that for the open system (the signal is highlighted in red in Figure 55). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

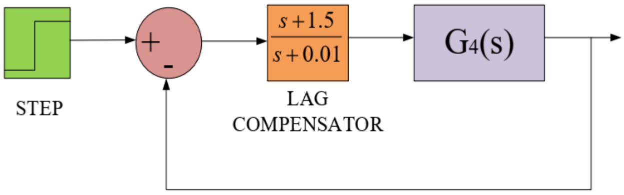

Figure 57. Simulink model of Lag compensators G4(s)

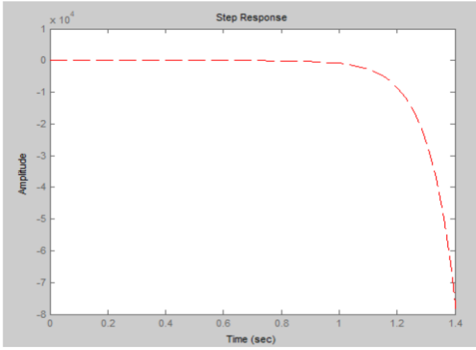

Figure 58. step response of the closed system for LAG compensator G4(s)

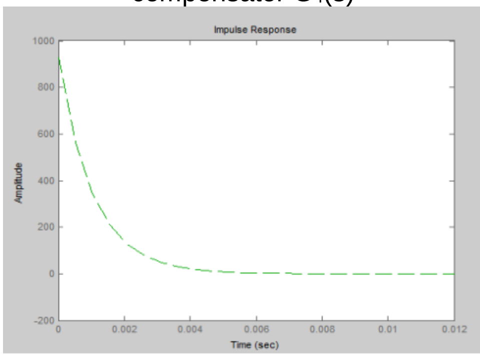

Figure 59. impulse response of the closed system for LAG compensator G4(s)

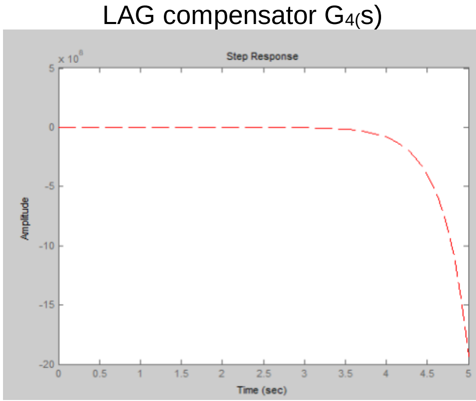

Figure 60. step response of the open system for LAG compensator G4(s)

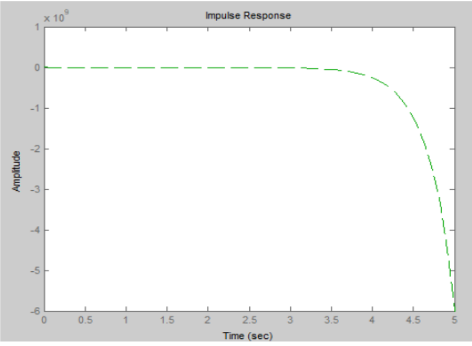

Figure 61. impulse response of the open system for LAG compensator G_4(s)

Figure 59: impulse response for the closed system (this signal is highlighted in green) is better than the open system (this signal is highlighted in green in Figure 61). The value of the amplitude of the oscillation of the closed system in this case is zero and the closed system reaches a steady state. For this type of LAG compensator, the closed system responds well. The value of the amplitude of the oscillation of the open system in this case is large and the open system does not reach a steady state. Figure 58: step response for the closed system (the signal is highlighted in red) is better than that for the open system (this signal is highlighted in red in Figure 60). The value of the amplitude of the oscillation of the closed system in this case is large and the closed system does not reach a steady state. For this type of LAG compensator, the closed system does not respond well. Meanwhile, the open system can not respond well.

Part 4: Model with using ANN

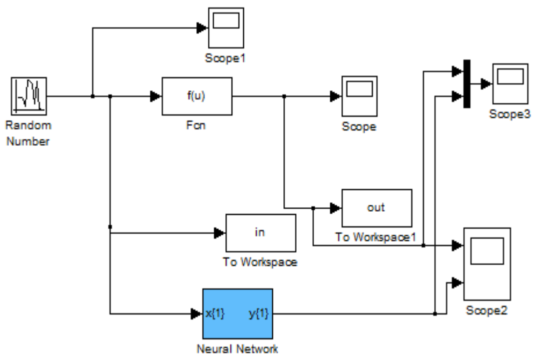

Figure 62.Simulink of model with using ANN

Figure 62: the value of f(u)= G_1(u)/ G_2(u)/G_3(u)/ G_4(u): the tranfer function of the system

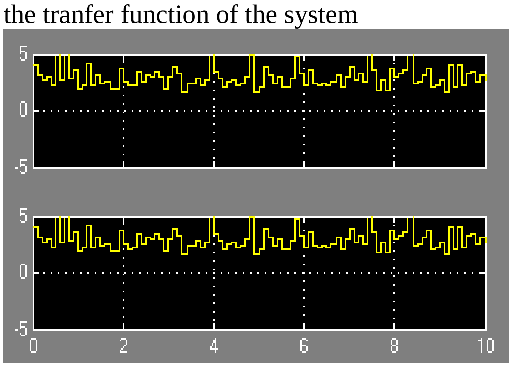

Figure 63. model with using ANN of Scope 2 ‘G_1(u)’

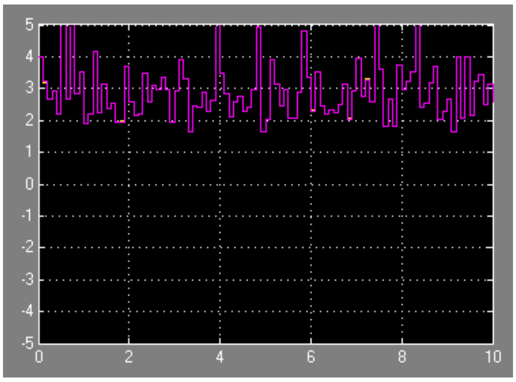

Figure 64. model with using ANN of Scope 3 ‘G_1(u)’

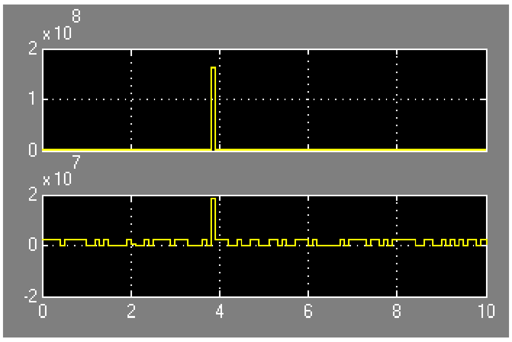

Figure 65. model with using ANN of Scope 2 ‘G_2(u)’

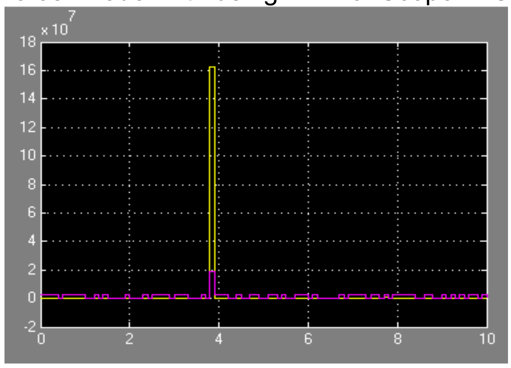

Figure 66. model with using ANN of Scope 3 ‘G_2(u)’

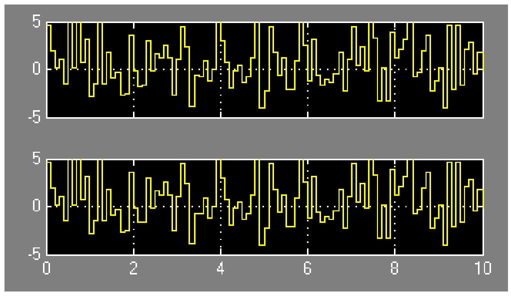

Figure 67. model with using ANN of Scope 2 ‘G_3(u)’

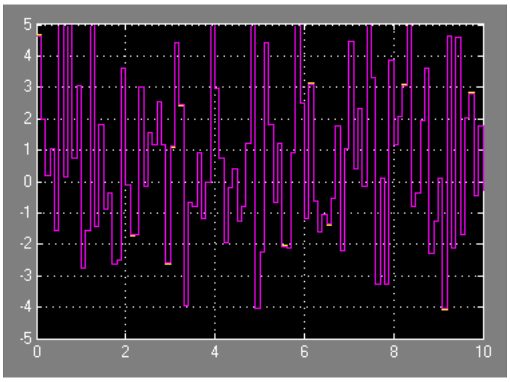

Figure 68. model with using ANN of Scope 3 ‘G_3(u)’

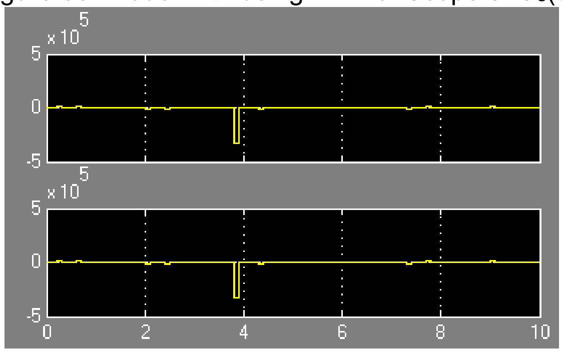

Figure 69. model with using ANN of Scope 2 ‘G_4(u)’

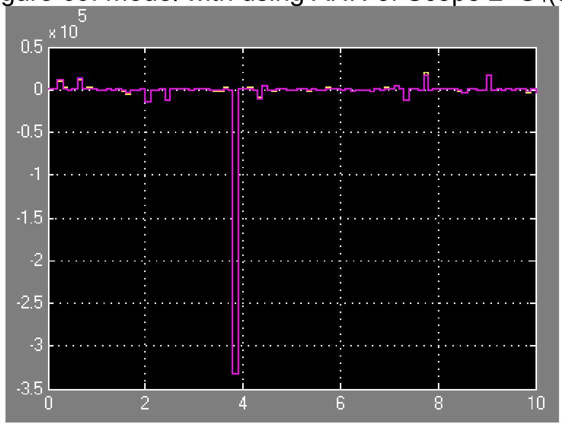

Figure 70. model with using ANN of Scope 3 ‘G_4(u)’

Figures 63, 64, 65, 66, 67, 68, 69, 70 are results of the output values. Figures 63, 65, 67, 69 are the result of the value of the output without using ANN (above image) and Figures 63, 65, 67, 69 also are the result of the output with using ANN (bottom image). Figures 64, 66, 68, 70 are a composite image of the value of the output without using ANN and the value of the output with using ANN. This result has an almost absolute match between two values above. Therefore, this is considered a successful survey in training the network to achieve desired results. The efficiency of using the above the controller/compensators for the system in descending order. This is based on states that are determined to be stable through simulation results. The number of simulation results with reaching steady state is the criterion to evaluate the effectiveness of the PID controller, Lead compensator, and Lag compensator applied to the above model:

A. ANN
B. PID controller
C. LEAD compensator /LAG compensator

7. Conclusions

To simplify and speed up the design process of control systems in general and Ac-robot in particular, the author's choices for the control presented above are consistent with the strategies laid out. Simulinks for the design of open loops as well as closed loops according to the design process. The analysis for the performance of the system was tested with PID controller, ANN, compensators. The purpose of this paper is for research and educational purposes. The experiment was used by various methods. The analysis obtained from curves of 2 responses showed that the strategies for controlling a system were implemented on the Matlab simulation. The accuracy and the applicability of these studies depend on the selection, performance analysis for a robotic system carefully. ANN can be a priority to be selected among above methods. In the process of implementing this topic, simulation results are stable for the system to be considered by the author.

References

[1] Gopi Krishna Rao P. V., Subramanyam M. V., Satyaprasad K.: “Performance Comparison of PID Controller Tuned using Classical and Genetic Algorithm Methods”, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 6, Number 14, pp. 1757-1766, (2011).
[2] Papoutsidakis M., Piromalis D., Neri F., Camilleri M.: “Intelligent Algorithms Based on Data Processing for Modular Robotic Vehicles Control”, WSEAS Transactions on Systems, volume 13, 2014.
[3] Nguyen H. T., Nguyen M. T., Nguyen V. D. H., Doan T. T., Vo C. P.: “Designing PID-Fuzzy Controller for Pendubot System”, Robotica & Management, Vol. 22 No. 2, pp. 8-12, December, 2017.
[4] Ramm A., Sjöstedt M.: “Reaction Wheel Balanced Robot, Design And Sensor Analysis Of Inverted Pendulum Robot”, Stockholm, Sweden 2015.
[5] Zhang A., She J., Lai X., Wu M.: “Motion Planning and Tracking Control for an Acrobat Base on a Rewinding Approach”, Automatica 49, 278-284, 2013.
[6 Abdul-Wahid A. Saif, “Strong stablization of the non linear Pendubot system”, 2015 IEEE 12th International Multi-Conference on Systems, Signals & Devices (SSD15), 2015.
[7 Tran Vinh Toan, Tran Thu Ha, Tran Vi Do, “Hybrid control for swing up and balancing pendubot system: An experimental result”, 2017 International Conference on System Science and Engineering (ICSSE), 2017.
[8] Xu Luo, Hongtao Wang, “a digital controller for the pendubot system using approximate output regulation approach”, 2010 2nd International Conference on Future Computer and Communication, 2010.
[9] Zixin Huang, Xuzhi Lai, “Control strategy based on iterative method for planar pendubot”, 2018, 37th Chinese Control Conference (CCC), 2018.

[10] Thamer Albahkali, Ranjan Mukherjee, Tuhin Das, "Swing-Up Control of the pendubot : An Impulse–Momentum Approach", IEEE Transactions on Robotics, 2009.

[11] Pongphut Awootsopa, Uthai Sritheerawirojana, Pitikhate Sooraksa, Noriyuki Komine, "Control of pendubot with Chaotic Perturbation", 2006 1ST IEEE Conference on Industrial Electronics and Applications, 2006.

[12] Mingjun Zhang, Tzyh-Jong Tarn, "Hybrid control for the Pendubot", Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No.01CH37164), 2001

[13] Su Xiaolu, Yu Yang, Ge Bin, "Application of ant colony algorithm in optimal control for the under-actuated system pendubot ", 2008 27th Chinese Control Conference.

[14] I. Fantoni, R. Lozano, M. W. Spong, "Energy based control of the pendubot ", IEEE Transactions on Automatic Control, 2000.

[15] Tzyh-Jong Tarn, Mingjun Zhang, F. Celani, "Hybrid control for the pendubot", 2000 26th Annual Conference of the IEEE Industrial Electronics Society. IECON 2000. 2000 IEEE International Conference on Industrial Electronics, Control and Instrumentation. 21st Century Technologies, 2000.

[16] Daniel I. Arevalo, Hussain Alazki, "Robust Control for Stabilization of Non-Inertial System: Pendulum- Ac-robot", 2018 15th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), 2018.

[17] Yibiao Luo, Xuzhi Lai, Min Wu, "A positioning control strategy of planar Acrobot", Proceedings of the 30th Chinese Control Conference, 2011.

[18] Fangzheng Xue, Zhicheng Hou, Hangjian Deng, "Balance control for an acrobot", 2011 Chinese Control and Decision Conference (CCDC), 2011.

[19] Nazih Hannouda, Hiroshi Takami, "control of acrobot using inverse linear quadratic method", 2018 International Conference on Control, Automation and Diagnosis (ICCAD), 2018.

[20] R. D. Doncker, D. W. J. Pulle, and A. Veltman. Advanced Electrical Drivers: Analysis, Modeling, Control. Springer, 2011.