RESEARCH ARTICLE OPEN ACCESS

Autonomous Vehicle Control, Part VII: Car Passenger Head Roll Angle Control using I-First Order, I-Second order compensators and PD-PI, 2DOF-2 Controllers Compared with a PID Controller

Galal Ali Hassaan
Department of Mechanical Design and Production, Faculty of Engineering, Cairo University, Egypt
Email: galalhassaan@ymail.com

--************************----------------------------------

Abstract:

This paper is the seventh in a series of research papers presenting the control of autonomous vehicles. It handles the control of automated-car-passenger-head using I-first order, I-second order compensators and PD-PI controllers from the second generation of control compensators and PID controllers compared with a PID controller from the first generation of PID controllers. Some efficient tuning techniques for the proposed compensators and controllers are applied. The step time response of the control system using the four investigated compensators/controllers is presented and compared and the time-based characteristics are extracted and compared. The comparison reveals the best compensator/controller among the four ones presented depending on a graphical and quantitative comparison study for reference input tracking.

Keywords — Autonomous control, passenger head roll angle control, I-first order compensator, I-second order compensator, PD-PI controller, PID controller, controller tuning.

.

--************************----------------------------------

I. INTRODUCTION

Autonomous vehicles are the latest technology in the transport technology. This series of research papers handles some aspects related to autonomous vehicles aiming at achieving high level of comfort of both driver and passengers. The present paper handles the problem of motion sickness of passengers due to their head rolling (tilting) during turning. We start by presenting a simple literature review about the subject since 1999 :

Zikovtz and Harris (1999) measured the head tilt of drivers and passengers at corners for different speeds. They showed that passenger head practiced tilting angle with range -26 to 5 degrees with eye open and -22 to -5 with eye closed [1]. Joseph and Griffin (2008) showed that mild nausea was reported by 17.5 % of subjects, mean illness ratings were 'least' with 1.83 degrees oscillation amplitude and 'greater' with 3.66 and 7.32 degrees [2]. Wada, Konno, Fujisawa and Doi (2012) presented an study for the development of a methodology to reduce carsickness. They presented the graphical vehicle lateral acceleration and the head roll angle for natural and active conditions. They concluded that active condition reduced the total symptom score for time from 5 to 10 minutes from driving termination [3]. Wada and Yoshida (2016) examined the effect of passenger's active head tilt and eyes open/closed conditions on the severity of motion sickness in lateral acceleration environment. They showed that the sickness rating with eyes open condition was much lower than that with eyes closed. Their results showed that the head tilting angle was 10.6 and 10.8 degrees with eys open and eyes closed respectively for centrifugal force condition [4].

Sarouchi et al. (2019) proposed a correlation model between lateral acceleration and head movement of driver and passengers using artificial neural network. They stated that mathematical model could be beneficial in the design of vehicle motion control systems to mitigate motion sickness effect. In a three driving data sets, the passenger head roll angle was in the range of -12 to 15 degrees [5]. Sarouchi et al. (2020) proposed the use of a fuzzy-PID control for a motion sickness control structure through diminishing the lateral acceleration. They used the head movement as the controlled variable of the control system and the steering wheel angle as its input. Their results achieved reduction in motion sickness incidence index by 3.95 % and 11.49 % for single and 10 laps [6]. Bohrmann (2021) addressed three research areas leading to the prevention of motion sickness in automated vehicles through vehicle interior investigation. They reported biomechanical differences in head motion as a result of backrest inclination. They stated that change in heart rate and core body temperature indicates sensitivity to motion sickness. They examined also the change in human performance due to malaise and nausea [7].

Driels, Ye, Bos and Maeda (2022) proposed the identification and development of appropriate vibration measurements and motion sickness assessment and evaluation methods. They addressed some questions about motion sickness regarding: most appropriate vehicle motion measures for motion sickness prediction and evaluation and most appropriate subjective motion sickness measures [8]. Siddiqi (2023) in his Ph. D. Thesis presented a cost function with definitive objective functions to minimize motion sickness in autonomous vehicles and evaluate the function using a developed prototype. He concluded that it was possible to constrain the lateral acceleration below the comfort range of 3.6 m/s2 by defining the track minimum radius to greater than 77 m. He used sliding mode control for vehicle lateral control producing threshold values of 2.964 and 2.869 m/s^2. He also investigated the use of PID and MPC controllers in his control scheme for lateral motion of the vehicle [9]. Wadi, Abdel-Hafiz and Jaradat (2024) investigated a method to mediate the onset of motion sickness in passenger autonomous vehicles. They estimated the internal forces acting on the passengers and analyzed them to reduce the motion sickness inducing components. They devised an approach to suppress lateral acceleration experienced by the passenger and reduce motion sickness. Their approach required equipping of the vehicle with an adaptive suspension system with active roll compensation. They stated that the application of their proposed methodology was reported to reduce the motion sickness dose value by 113 % on average [10].

II. THE CONTROLLED PASSENGER HEAD ROLL AS A PROCESS

Abdelazeim et al. used an undelayed second-order model for a passenger head roll motion with RMSE of 2.5419 as a best model identified [11]. Their transfer function model for the passenger head roll as a process, $G_p(s)$ is given by [11]:

$G_p(s) = (27.35s+0.5556)\ (s^2+6.607s+1.602)$ (1)

To investigate the dynamics of the passenger head roll angle, a unit step time response is generated using the 'step' command of MATLAB [12] which is shown in Fig.1.

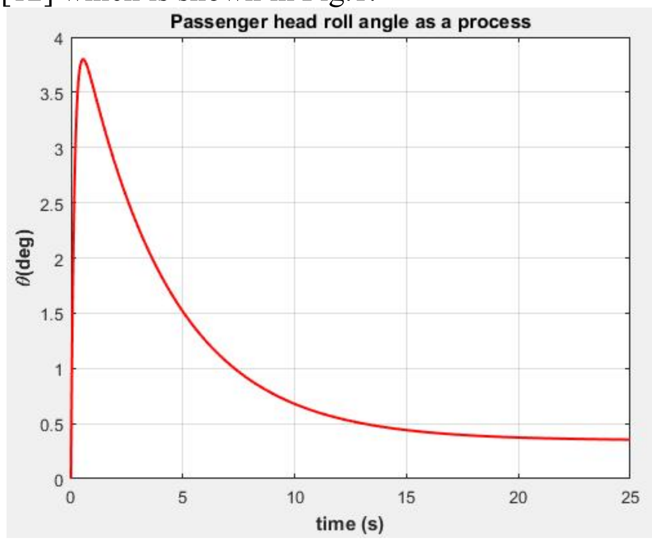

Fig.1 Passenger head roll angle step time response.

COMMENTS:

- Maximum overshoot: 971.85 %
- Maximum undershoot: zero
- Settling time: 22.50 s
- Steady-state error: 0.6456 deg

- This process dynamically has very bad dynamics because of its very large maximum overshoot and large settling time.

III. CONTROLLING THE PASSENGER HEAD ROLL USING AN I-FIRSR ORDER COMPENSATOR

- The I-first order was compensator was used by the author since 2024 as a member of the second generation compensators introduced by the author since 2014. He used the I-first order compensator to control an autonomous car longitudinal velocity [13] and the car sideslip angle [14]. The structure of the I-first order compensator is shown in Fig.2 located in the feedforward path of a single loop control system incorporating the compensator and the controlled process [13].

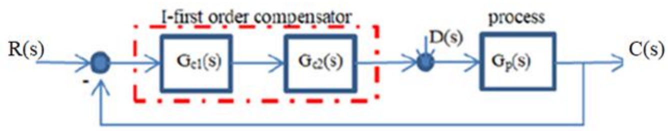

Fig.2 Block diagram incorporating the I-first order compensator [13].

- The compensator has two control elements of transfer functions $G_{c1}(s)$ and $G_{c2}(s)$ given by:

$G_{c1}(s) = K_i/s$, $G_{c2}(s) = (s+z)/(s+p)$ (2)

Where: K_i = integral gain of the compensator.
z = simple zero of the compensator.
p = simple pole of the compensator.

- The I-first order compensator has three parameters to be tuned to adjust the performance of the control system. It is tuned as follows:
  - o The transfer function of the controlled process (passenger-head roll angle) of Eq.1 has one zero and two poles given as:

Zero: $s + 0.0203$
Poles: $s + 6.7549$ and $s + 0.2521$ (3)

  - o The zero/pole cancellation technique is applied to define the zero and pole of the compensator [15].
  - o One of the poles of the compensator is chosen to cancel the zero of the head roll angle (s+0.0203) and its zero is chosen to cancel the head roll angle pole (s+6.3549).
  - o This approach gives the zero and pole of the compensator in Eq.2 as:

$z = 6.3549$ and $p = 0.0203$ (4)

  - o Few values for the compensator gain K_i was tried without any optimization giving good performance for the I-first order compensator when used to control the passenger head roll angle. According to this approach, the gain K_i is selected as:

$K_i = 10$ (5)

  - o The unit step time response for reference input tracking using the process in Eq.1, the compensator in Eq.2 and the compensator parameters in Eqs.4 and 5 is obtained using the command 'step' of MATLAB [12] as shown in Fig.3

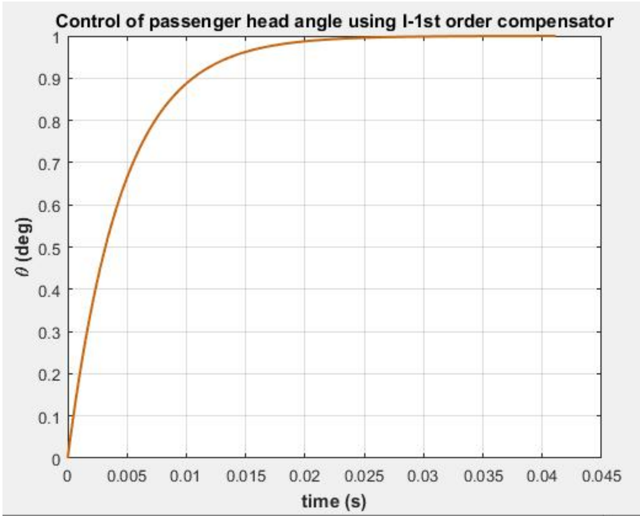

Fig.3 Passenger head roll angle control using an I-first order compensator.

COMMENTS:

- ➢ Maximum overshoot: zero
- ➢ Maximum undershoot: zero
- ➢ Settling time: 0.0179 s
- ➢ Steady-state error: zero

IV. CONTROLLING THE PASSENGER HEAD ROLL USING AN I-SECOND ORDER COMPENSATOR

- The I-second order compensator was proposed by the author to control an autonomous car yaw rate [16]. It replaces the I-first order compensator in Fig.2. It has the transfer functions, $G_{c1}(s)$ and $G_{c2}(s)$ given by:

$$G_{c1}(s) = K_i/s$$
$$G_{c2}(s) = (s^2+c_1s+c_2)/(s^2+d_1s+d_2) \quad (6)$$

- It has five parameters: K_i, c_1, c_2, d_1 and d_2 to be tuned to adjust the control system performance.
- Again, the zero-pole cancellation technique [15] is used to cancel the quadratic pole of the passenger head roll angle model in Eq.1. This reveals the zeros of $G_{c2}(s)$ as:
  $$c_1 = 6.607 \text{ and } c_2 = 1.602 \quad (7)$$
- We are lift now with the compensator parameters K_i, d_1 and d_2. A successful trial is applied without any optimization giving:
  $$K_i = 0.695 \text{ , } d_1 = 10 \text{ and } d_2 = 0.01 \quad (8)$$
- The unit time response of the control system incorporating the I-second order compensator using Eqs.1 for the process, 6 for the compensator, 7 and 8 for its parameters is drawn by the help of MATLAB 'step' command [12] and shown in Fig.4.

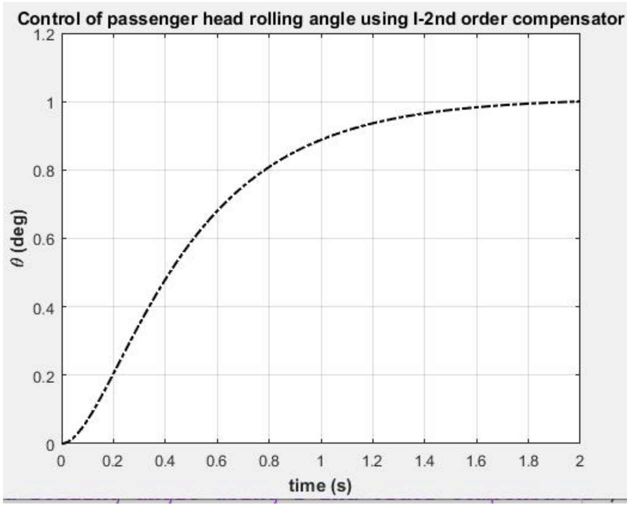

Fig.4 Passenger head roll angle control using an I-second order compensator.

COMMENTS:

- Maximum overshoot: zero
- Maximum undershoot: zero
- Settling time: 1.556 s
- Steady-state error: zero

V. CONTROLLING THE PASSENGER HEAD ROLL ANGLE USING A PD-PI CONTROLLER

The PD-PI controller was introduced by the author in 2014 as one of the good controllers of the second generation of the PID controllers. The author tested the performance of the PD-PI controller through its use in controlling first-order delayed processes [17], highly oscillating second-order process [18], integrating plus time-delay process [19], delayed double integrating process [20], third-order process [21], boost-glide rocket engine [22], rocket pitch angle [23], LNG tank pressure [24], boiler temperature [25] boiler-drum water level [26], greenhouse internal humidity [27], coupled dual liquid tanks [28], BLDC motor [29], furnace temperature [30], electro-hydraulic drive [31], barrel temperature [32], mold packing pressure [33], IMM ram velocity [34], full-electric IMM [35], Al-Jazari hydraulic turbine [36], Banu Musa axial turbine power control [37], wind turbine speed [38], steam turbine speed [39], autonomous car steering angle [40], autonomous car sideslip angle [14] and autonomous car yaw rate [16].

The block diagram of the control system incorporating a PD-PI controller comprises a PD-control and PI-control modes in series after the error detector feeding its output directly to the controlled process.

The PD-PI controller has a transfer function, $G_{PDPI}(s)$ given by [27]:

$$G_{PDPI}(s) = [K_dK_{pc2}s^2+(K_dK_i+K_{pc1}K_{pc2})s+K_{pc1}K_i]/s \quad (9)$$

Where:

K_{pc1} = proportional gain of the PD-control mode.

K_d = derivative gain of the PD-control mode

K_{pc2} = proportional gain of the PI-control mode.

K_i = derivative gain of the PI-control mode

The PD-PI controller has four gain parameters to be tuned to optimal performance for the control system.

- The transfer function of the control system comprising the PD-PI controller and the controlled process is derived using the block diagram of the control system and Eqs.1 and 9.

- The performance index to me minimized by the optimization technique was selected as the ITAE [41].
- The MATLAB optimization toolbox [42] is selected to perform the minimization of the ITAE and provide the optimal gain parameters of the PD-PI controller.
- The tuned parameters of the PD-PI controller are as follows:

K_{pc1} = 0.0549938 , K_d = 0.050250

K_{pc2} = 0.0502500 , K_i = 0.443964 (10)

- Using the closed-loop transfer function of the closed-loop control system and the PD-PI controller gains in Eq.10 for reference input tracking, the unit step response is generated using the MATLAB command '*step*' [12] and shown in Fig.5.

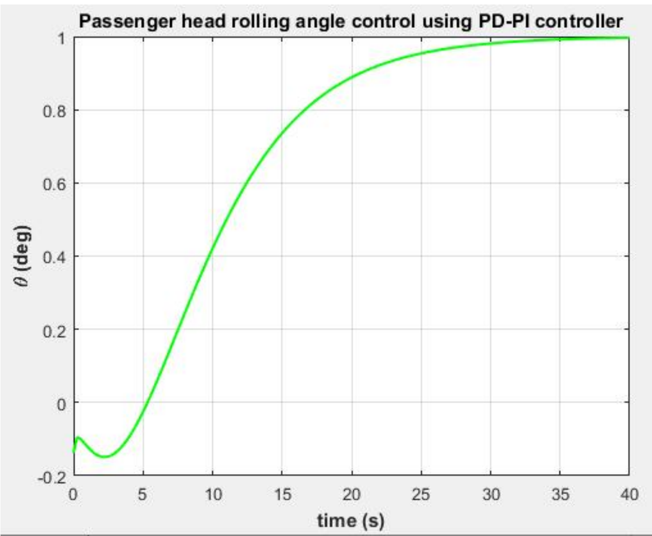

Fig.5 Passenger head roll angle control using a PD-PI controller.

COMMENTS:

- Maximum overshoot: zero
- Maximum undershoot: 0.149 deg
- Settling time: 29.72 s
- Steady-state error: zero

VI. CONTROLLING THE PASSENGER HEAD ROLL ANGLE USING A PID CONTROLLER

PID controller is one of the first generation of PID controllers. The PID controller is still in use in many automatic control applications [43-46].

- The PID controller is set in the forward path of a single-loop control system incorporating a classical controller and the controlled process. It receives its input from the error detector and feeds its output to the process.
- It has the transfer function, $G_{PID}(s)$:

$$G_{PID}(s) = K_{pc} + (K_i/s) + K_d s \qquad (11)$$

Where K_{pc} is its proportional gain, K_i is its integral gain and K_d is its derivative gain.

- The transfer functions of the closed-loop control system are derived from the block diagram using the train speed transfer function in Eq.1 and the PID controller transfer function in Eq.11 for reference input tracking.
- The PID controller is tuned by the same tuning procedure used with the PD-PI controller revealing the following gain parameters:

K_{pc} = 0.9844638 , K_i = 0.4165868

K_d = 0.0008999 (12)

- The closed-loop transfer functions of the process (Eq.1) and PID controller (Eq.11) with tuned gain parameters (Eq.12) are used to plot the unit step input step time response of the control system using the '*step*' command of MATLAB [12] as shown in Fig.10 for the train velocity and Fig.6.

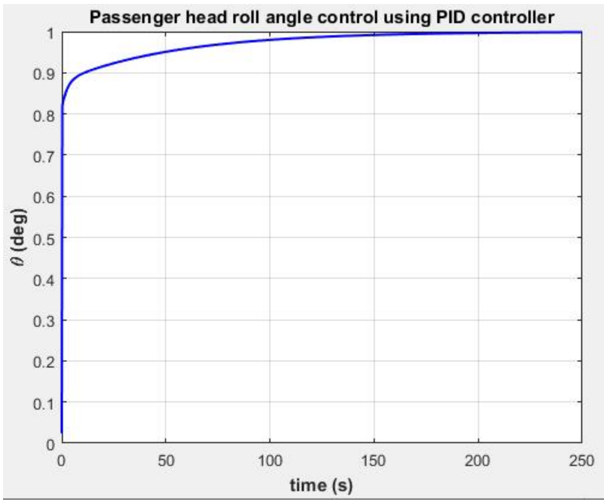

Fig.6 Passenger head roll angle control using a PID controller.

COMMENTS:

- Maximum overshoot: 0.004 %
- Maximum undershoot: zero
- Settling time: 100.3 s
- Steady-state error: zero

VII. COMPARISON ANALYSIS

- To evaluate the effectiveness of using the proposed compensators/controllers, the step time response for reference input is compared with that using a tuned PID controller.
- A graphical comparison is presented in Fig.7 for reference input tracking and a unit step input.

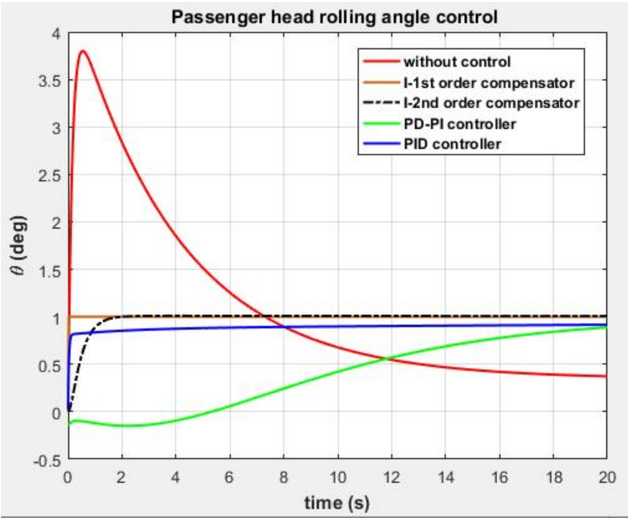

Fig.7 Passenger head roll angle control using two compensators and two controllers

- A quantitative comparison for the time-based characteristics of the control systems proposed to control the car passenger head roll angle is given in Table 1 for a reference step input tracking.

TABLE 1

TIME-BASED CHARACTERISTICS OF THE PASSENGER HEAD ROLL ANGLE CONTROL FOR REFERENCE INPUT TRACKING

Compensator/ Controller/	I-1st order compensator	I-2nd order compensator	PD-PI controller	PID controller
OS_{max} (%)	0	0	0	0.004
US_{max} (s)	0	0	0.149	0.024
T_s (s)	0.0179	1.556	27.72	100.3
e_{ss} (deg)	0	0	0	0

OS_{max} = maximum percentage overshoot
US_{max} = maximum undershoot
T_s = settling time to 2 % tolerance.
e_{ss} = steady-state error..

VIII. CONCLUSIONS

- This research paper investigated the use of I-first order and I-second order compensators and PD-PI controllers from the second generation of PID controllers to control the city.
- The process under control (passenger head roll angle) was an example of processes with bad dynamics because of its large maximum overshoot, settling time and steady-state error.
- The performance of the proposed controllers was compared with that of a PID controller from the first generation of PID controllers.
- Two tuning techniques were used in this study: manual settling of the compensator parameters based on specific criteria and using the MATLAB optimization toolbox.
- There was zero maximum overshoot for I-first order, I-second order compensators and PD-PI controller for reference input tracking.
- The settling time of the step input tracking was 0.0179, 1.556 and 27.72 s for the I-first order, I-second order compensators and PD-PI controller compared with 100.3 s for the PID controller
- The PD-PI controller practiced a maximum undershoot of 0.149 deg compared with 0.024 deg for the PID controller.
- Obviously, the I-first order compensator proved in this application to be the best compensator/controller because of the outstanding characteristics of the closed loop control system comprising it and the controlled process (car passenger head roll angle).
- The I-second order compensator comes next to the I-first order compensator as the second-best compensator/controller..

REFERENCES

[1] D. Zikovitz and L. Harris, "Head tilt during driving", *Ergonomics*, vol.42, issue 5, pp.740-746, 1999.

[2] J. Joseph and M. Griffin, “Motion sickness: effect of the magnitude of roll and pitch oscillation”, *Aviation, Space and Environmental Medicine*, vol.79, issue 4, pp.390-396, 2008.

[3] T. Wada, H. Konno, S. Fujisawa and S. Doi, “Car passenger’s active head tilt decrease the severity of carsickness”, *Human Factors*, vol.54, issue 2, pp.71-78, 2012.

[4] T. Wada and K.Yoshida, “Effect of passenger’s active head tilt and opening/closure of eyes on motion sickness in lateral acceleration environment of cars”, *Ergonomics*, vol.49, issue 8, pp.1050-1059, 2016.

[5] S. A. Saruchi et al., “Artificial neural network for modeling of the correlation between lateral acceleration and head movement in a motion sickness study”, *IET Intelligent Transport Systems*, vol.13, issue 2, pp.3400-346, 2019.

[6] S. A. Sarauchi et al., “Novel motion sickness minimization control via fuzzy PID controller for autonomous vehicles”, *Applied Sciences*, vol.10, issue 4769, 13 pages, 2020.

[7] D. K. Bohramann, “Motion comfort: Physical-geometric optimization of the vehicle interior to enable non-driving related tasks in automated driving scenarios with the focus on motion sickness mitigation”. *Thesis*, TUM School of Engineering and Design, Technische Universitat Munchen, 2021.

[8] C. Diels, Y. Ye, J. Bos and S. Maeda, “Motion sickness in automated vehicles: principal research questions and the need for common protocols”, *SAE International Journal of CAV*, vol.5, issue 2, 22 pages, 2022.

[9] M. R. Siddiqi, “Minimizing motion sickness in autonomous vehicles”, *Ph. D. Thesis*, School of Engineering, Royal Melbourne Institute of Technology, April 2023.

[10] A. Wadi, M. Abdel-Hafez and M. Jaradat, “Mitigating motion sickness in autonomous vehicles for improved passenger comfort”, *IEEE Access*, vol.12, pp.62709-62718, 2024.

[11] Y. Abdelaziem, Y. Ali and A. Saruchi, “Comparison of transfer function models to represent the correlation between vehicle lateral acceleration and head tilting angle in motion sickness”, *International Journal of Automotive and Mechanical Engineering*, vol.19, issue 4, pp.10039-10049, 2022.

[12] Mathworks, “Step response of dynamic system”, https://www.mathworks.com/help/ident/ref/dynamicsystem.step.html , 2023.

[13] G. A. Hassaan, “Autonomous vehicle control, Part I: Car longitudinal velocity control using P-D, I-first order and notch compensators compared with a PID controller,” *International journal of Research Publication and Reviews*, vol.5, issue 9, pp. 224-234, 2024.

[14] G. A. Hassaan, “Autonomous vehicle control, Part V: Car sideslip angle control using P-D, I-first order compensators and PD-PI, 2DOF-2 controllers compared with a PID controller,” *International journal of Progressive Research in Engineering Management and Science,* vol.4, issue 10, pp. 424-432, 2024.

[15] S. Abe et al., “Pole-zero cancellation technique for DC-DC converter”, *Advances in PID Control*, September 2011, DOI: 10.5772/18590.

[16] G. A. Hassaan, “Autonomous vehicle control, Part IV: Car yaw rate control using P-D, I-second order compensators and PD-PI, 2DOF-2 controllers compared with a PID controller”, *World Journal of Engineering Science and Technology*, vol.10, issue 11, pp.1-20, 2024.

[17] G. A. Hassaan, “Tuning of PD-PI controller used with first-order delayed process”, *International Journal of Engineering Research and Technology*, vol.3, issue 4, pp.51-55, 2014.

[18] G. A. Hassaan, “Tuning of PD-PI controller used with a highly oscillating second-order process”, *International Journal of Science and Technology Research*, vol.3, issue 7, pp.145-147, 2014.

[19] G. A. Hassaan, “Tuning of PD-PI controller used with an integrating plus time delay process”, *International Journal of Scientific & Technical Research*, vol. 3, issue 9, pp. 309-313, 2014.

[20] G. A. Hassaan, “Controller tuning for disturbance rejection associated with delayed double integrator process, Part I: PD-PI controller”, *International Journal of Computer Techniques*, vol.2, issue 3, pp.110-115, 2015.

[21] G. A. Hassaan, “Tuning of PD-PI controller used with a third-order process”, *International Journal of Application or Innovation in Engineering Management*, vol.9, issue 8, pp.6-12, 2020.

[22] G. A. Hassaan, “Control of a boost-glide rocket engine using PD-PI, PI-PD and 2DOF controllers”, *International Journal of Research Publication and Reviews*, vol.4, issue 11, pp.913-923, 2023.

[23] G. A. Hassaan, “Control of rocket pitch angle using PD-PI controller, feedback first-order compensator and I-PD compensator”, *International Journal of Computer Techniques*, vol.11, issue 1, 8 pages, 2024.

[24] G. A. Hassaan, “Liquefied natural gas tank pressure control using PID, PD-PI, PI-PD and 2DOF controllers”, *World Journal of Engineering Science and Technology*, vol.10, issue 2, pp.18-33, 2024.

[25] G. A. Hassaan, “Control of boiler temperature using PID, PD-PI and 2DOF controllers”, *International Journal of Research Publication and Reviews*, vol.5, issue 1, pp.5054-5064, 2024.

[26] G. A. Hassaan, “Control of Boiler-drum water level using PID, PD-PI, PI-PD and 2DOF controllers”, *International Journal of Engineering and Techniques*, vol.10, issue 1, 10 pages, 2024.

[27] G. A. Hassaan, “Tuning of PD-PI and PI-PD controllers to control the internal humidity of a greenhouse”, *International Journal of Engineering and Techniques*, vol.9, issue 4, 9 pages, 2023.

[28] G. A. Hassaan, “Tuning of controllers for reference input tracking of coupled-dual liquid tanks”, *World Journal of*

Engineering Science and Technology, vol.8, issue 2, pp.86-101, 2022.
[29] G. A. Hassaan, "Tuning of controllers for reference input tracking of a BLDC motor", *International Journal of Progressive Research in Engineering, Management and Science*, vol.2, issue 4, pp.5-14, 2022.
[30] G. A. Hassaan, "Furnace control using I-PD, PD-PI and 2DOF controllers compared with fuzzy-neural controller", *International Journal of Computer Techniques*, vol.11, issue 2, 10 pages, 2024.
[31] G. A. Hassaan, "Control of an electro-hydraulic drive using PD-PI, PI-PD and 2DOF-2 controllers compared with a PID controller", *International Journal of Engineering and Techniques*, vol.10, issue 2, 10 pages, 2024.
[32] G. A. Hassaan, "Thermoplastics injection molding machine control, Part II: Barrel temperature control using PD-PI, PI-PD and 2DOF-2 controllers compared with ANN-PI controller", *International Journal of Engineering and Techniques*, vol.10, issue 3, pp.6-15, 2024.
[33] G. A. Hassaan, "Thermoplastics injection molding machine control, Part IV: Mold packing pressure control using I-PD, PD-PI, PI-PD and 2DOF-2 controllers compared with an adaptive IMC controller", *World Journal of Engineering Research and Technology*, vol.10, issue 6, pp.94-114, 2024.
[34] G. A. Hassaan, "Thermoplastics injection molding machine control, part V:Ram velocity control using I-PD, PD-PI, PI-PD and 2DOF-3 controllers compared with improved PID controller", *International Journal of Computer Techniques,* vol.11, issue 3, pp.42-52, 2024.
[35] G. A. Hassaan, "Thermoplastics injection molding machine control, part VI: Full-electric injection molding machine control using PD-PI, PI-PD and 2DOF-4 controllers compared with a PI controller", *International Journal of Engineering and Techniques*, vol.10, issue 3, pp.157-166, 2024.
[36] G. A. Hassaan, "Power turbines control, part I: Al-Jazari turbine control using I-PD, PD-PI, 2DOF-3 and PI-PD controllers compared with a PI controller", *International Journal of Research Publication and Reviews*, vol.5, issue 7, pp.175-186, 2024.
[37] G. A. Hassaan, "Power turbines control, part II: Banu Musa axial turbine power control using PD-PI, PI-PD and 2DOF-3 controllers compared with a PI controller", *International Journal of Engineering and Techniques*, vol.10, issue 4, pp.86-97, 2024.
[38] G. A. Hassaan, "Power turbines control, part III: Wind turbine speed control using PD-PI, PI-PD and 2DOF-3 controllers compared with a PI controller", *International Journal of Computer Techniques*, vol.11, issue 4, pp.11-21, 2024.
[39] G. A. Hassaan, "Power turbines control, part IV: Steam turbine speed control using 2/2 second-order, I-PD compensators and PD-PI, 2DOF-3 controllers compared with a PI controller", *World Journal of Engineering Research and Technology*, vol.10, issue 9, pp.112-132, 2024.
[40] G. A. Hassaan, "Autonomous vehicle control, part II: Car steering angle control using PD-PI, PI-PD and 2DOF-3 controllers compared with a PID controller", *International Journal of Engineering and Techniques*, vol.10, issue 5, pp.1-12, 2024.
[41] F. G. Martins, "Tuning PID controllers using the ITAE criterion", International Journal of Engineering Education, vol.21, issue 3, 7 pages, 2005.
[42] C. Lopez, "MATLAB optimization techniques", *Apress*, 2014.
[43] A. Shuaib and M. Ahmed, "Robust PID control system design using ITAE performance index (DC motor model)", *International Journal of Innovative Research in Science, Engineering and Technology*, vol.3, issue 8, pp.15060-15067, 2014.
[44] V. Alfaco and R. Vilanova, "PID control: Resilience with respect to controller implementation", Control and Automation Systems, vol.3, 13 pages, 2022.
[45] Z. Li, "Review of PID control design and tuning methods", Journal of Physics: Conference Series, vol.2649, 6 pages, 2023.
[46] R. Patil, S. Jadhav and M. Patil, "Review of intelligent and nature-inspired algorithms- based methods for tuning PID controllers in industrial applications", Journal of Robotics and Control, vol.5, issue 2, 336-357, 2024.

BIOGRAPHY

GALAL ALI HASSAAN

- Emeritus Professor of System Dynamics and Automatic Control.
- Has got his B.Sc. and M.Sc. from Cairo University in 1970 and 1974.
- Has got his Ph.D. in 1979 from Bradford University, UK under the supervision of Late Prof. John Parnaby.
- Now with the Faculty of Engineering, Cairo University, EGYPT.

- Research on Automatic Control, Mechanical Vibrations, Mechanism Synthesis and History of Mechanical Engineering.
- Published more than 330 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Honourable Chief Editor of the International Journal of Computer Techniques.
- Reviewer in some international journals.
- Scholars interested in the authors publications can visit:

  http://scholar.cu.edu.eg/galal