International Journal of Engineering and Techniques - Volume 10 Issue 6, November 2024

RESEARCH ARTICLE OPEN ACCESS

Autonomous Vehicles Control, Part VI: Car Lateral Acceleration Control using I-PD, PD-PI and 2DOF-2 Controllers Compared with a PID Controller

Galal Ali Hassaan

Department of Mechanical Design & Production, Faculty of Engineering, Cairo University, Egypt

Abstract:

This paper investigates the tuning of I-PD, PD-PI and 2DOF-2 controllers from the second generation of PID controllers when used to control the lateral acceleration of an autonomous car. The controllers are tuned using MATLAB optimization toolbox and the ITAE performance indices. The tuning results are presented and applied to generate the unit step time response for reference input tracking. A one zero-three poles transfer function is fitted to an experimental data from previous work. The characteristics of the step time responses are compared with those of a PID conventional controller from the first generation of PID controllers. The best controller for the control of the car lateral acceleration is assigned.

***Keywords* — Autonomous cars, lateral acceleration control, I-PD controller, PD-PI controller, 2DOF-2 controller, PID controller, controller tuning.**

I. INTRODUCTION

Lateral acceleration during turning is an important parameter affecting vehicle roll angle and passenger motion sickness. Thus, controlling vehicle lateral acceleration leads directly to the control of rolling angle and motion sickness. This is the six research paper in the series of research papers aiming at investigating the introduction of the second generation of PID controllers to replace old controllers from the first generation of PID controllers. In the present work the author presents the control of the lateral acceleration of an autonomous car using three controllers from the second generation of PID controllers to strengthen the need to change to this new generation by researchers and designers of control systems and automotive engineers.

Here are some of the research efforts regarding control of the autonomous car lateral acceleration:

Olsson (2015), focused in his thesis on lateral and longitudinal control of autonomous vehicles and considered two control strategies: a decoupled control and a coupled control. The coupled controller was a linear time varying model predictive controller handling both lateral and longitudinal controls. He presented the findings of the two control strategies and evaluated their performance and ease of application [1]. Elhefnawy, Sharaf, Ragheb and Hegazy (2017) presented an advanced coordination of integrated control systems considering of an electronic stability control, an active front steering and an active suspension using fuzzy logic control for the purpose of improving vehicle handling, cornering stability and rollover prevention with anti-lock braking system. They introduced a reference yaw-roll plane vehicle model to compare and control the yaw rate, sideslip angle and roll angle of the vehicle body. Their coordination chassis control was based on the lateral acceleration value as input and the fuzzy logic control and the outputs were fed to the three controllers. They applied different standard test maneuvers: J-turn, fishhook and double lane change with different driving speeds. They provided step-based dynamic models for lateral acceleration, sideslip angle and yaw rate of the vehicle [2]. Novi et al. (2018) explored if the decrease in 'static margin' can lead to a performance advantage on obstacle avoidance manoeuvre when a robot controller is used. This was achieved by analysing the behaviour of various vehicle models with different 'static margin' and peak lateral acceleration on non-standard double lane change manoeuvre [3].

Chokor, Talj, Doumiati and Charara (2020) discussed the effects of roll control on vehicle performance (rollover avoidance and lateral stability). They designed a dynamic reference generator function of the vehicle lateral acceleration for control purpose. They investigated how roll control can help the vehicle to avoid the rollover without deceleration or steering action. They compared between roll angle control towards static and dynamic references and concluded that the vehicle roll control could improve lateral stability and rollover avoidance [4]. Zakaria, Zamzuri and Saruchi et al. (2021) investigated the phenomenon of the suffer of passengers of autonomous vehicles of 'motion sickness' during cornering. They proposed a lateral control approach based on the 'head roll angle' estimated by head roll prediction models to reduce 'motion sickness' severity. They used a PI controller to produce a corrective steering wheel angle to decrease the lateral acceleration leading to reducing the head roll angle [5]. Abdelaziem, Ali and Saruchi (2022) proved that 'motion sickness incidence (MSI)' could be predicted through mathematical models. They utilized experimental data from prior study to develop the mathematical models with different proportions to represent the correlation between vehicle movement and occupant behaviour in 'motion sickness' in transfer function equations. They obtained three different transfer function orders: second, third and fourth for each proportion used for driver and passenger. They investigated the efficiency of the models using the root mean square error [6].

Moharrami and Mohammadi (2023) introduced an innovative approach to adaptive cruise control systems for safety, comfort and efficiency driving characteristics. Their approach helped the vehicle to stay laterally stable by limiting the vehicle lateral acceleration. They presented a flowchart for their proposed control system and the host lateral acceleration showing the acceleration limit in g [7]. Assi, Amer and Ozkan (2024) presented an adaptive model predictive controller controlling the yaw rate and lateral acceleration of a ground vehicle. They applied experiments on a realistic vehicle based on a nonlinear brush tire model. They proposed a method for estimating tire cornering stiffness with high estimation efficiency, robustness, stability, comfort, accuracy under a variety of steering input maneuvers. They presented the lateral acceleration time response for vehicle with controller and controller with estimation and without control [8].

II. THE CONTROLLED LATERAL ACCELERATION AS A PROCESS

Elhefnawy, Sharaf, Ragheb and Hegazy (2017) presented data for an autonomous vehicle steering during J-turn manoeuvre with and without control for a number of vehicle lateral functions including lateral acceleration for a 90 degrees maximum steering angle (1.5708 rad) at vehicle speeds of 30 and 40 m/s [2]. I tried to model a reasonable transfer function for the given date using an ITAE performance index [9] and the MATLAB optimization toolbox [10]. The best model I have got had a multiple correlation coefficient of 0.9817 between the model and data of reference [2] using the command 'corrcoef' of MATLAB [11]. It is composed of one zero, one simple pole and a quadratic pole. The lateral acceleration has an open-loop transfer function, $G_p(s)$ given by:

$$G_p(s) = K_p\omega_n^2(T_zs+1)/[(T_ps+1)(s^2+2\zeta\omega_ns+\omega_n^2)] \quad (1)$$

Where:

K_p is the process gain (4.541 (m/s^2)/rad).

T_z is the time constant of the simple zero.

T_p is the time constant of the simple polo.

ω_n is the natural frequency of the quadratic pole.

ζ is the damping ratio of the quadratic pole.

The identified process parameters in Eq.1 using the optimization toolbox of MATLAB are:

$$T_z = 0.235 \text{ s} \quad , \quad T_p = 0.021 \text{ s}$$
$$\omega_n = 3.85 \text{ rad/s} \ , \ \zeta = 0.61 \qquad (2)$$

The unit step time response of the lateral acceleration process using the model in Eq.1 and parameters in Eq.2 and the data in reference [2] is evaluated and drawn using the '*step*' command of MATLAB [12]. It is shown in Fig.1.

The time based characteristics of the lateral acceleration process using the model in Eq.1 and its step time response in Fig.1 are:

- Maximum percentage overshoot: 20.21 %
- Settling time: 1.815 s
- Steady-state error: -5.5622 m/s^2

This process is another example of processes with bad dynamics. It has large maximum overshoot and large steady-state error. Any proposed controlled has to face those challenges and produce control system for the lateral acceleration with smooth change of acceleration, accurate time response and with good stability to achieve comfortable maneuvering during turning.

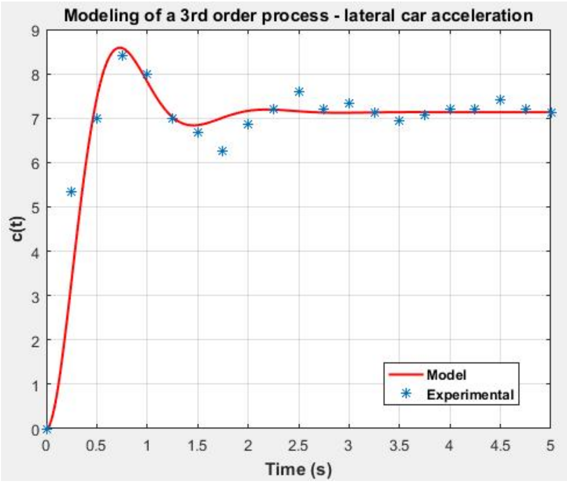


Fig.1 Lateral acceleration step time response as a process.

III. LATERAL ACCELERATION CONTROL USING AN I-PD CONTROLLER

- The I-PD controller is one of the second generation controllers introduced by the author starting from 2014 to replace the first generation of PID controllers. The author used I-PD controller to control a variety of industrial processes with bad dynamics such as: some second-order processes [13], a highly oscillating second-order process [14], [15], oscillating third-order process [16], delayed double integrating process [17], furnace temperature [18], IMM cavity gate pressure [19], IMM mold packing pressure [20], Al-Jazari turbine speed [21].
- The structure of the I-PD controller in a single loop control loop for the control of the lateral acceleration of an autonomous vehicle in turning maneuver is shown in Fig.2.

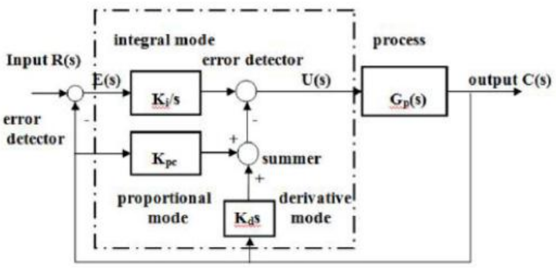


Fig.2 I-PD controller structure [18].

- An I-PD controller comprises three control elements of integral, proportional and derivative actions arranged as depicted in Fig.2. It has three gain parameters:

K_i: integral gain of the I-control mode.

K_{pc}: proportional gain of the P-control mode.

K_d: derivative gain of the D-control mode.

- The I-PD controller is tuned by the minimization of an ITAE performance index function of the error between the input and the time response of the lateral vehicle acceleration [9] using the MATLAB optimization toolbox [10].
- The tuning results are as follows:

$K_i = 8.8174725$; $K_{pc} = 1.3788528$

$K_d = 0.00488205$ (3)

- Using the block diagram in Fig.2, the process transfer function in Eq.1 and the I-PD controller elements transfer functions, the transfer function of the control system between the vehicle lateral acceleration as output and the steering angle as input can be easily derived.
- The 'step' command of MATLAB is used to plot the unit step time response of the control system [12] using the derived closed-loop transfer function. It is shown in Fig.3.

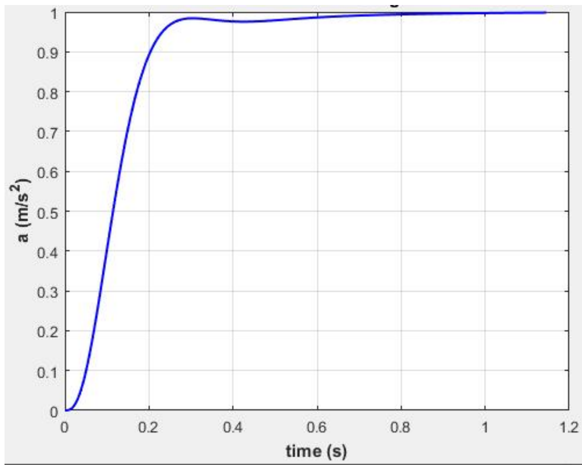


Fig.3 Lateral acceleration control using an I-PD controller.

COMMENTS:

- Maximum overshoot: zero
- Settling time: 0.514 s
- Steady-state error: zero

IV. LATERAL ACCELERATION CONTROL USING A PD-PI CONTROLLER

- The PD-PI controller is one of the second generation controllers introduced by the author starting from 2014 to replace the first generation of PID controllers. The author used PD-PI control to control a variety of industrial processes with bad dynamics such as: highly oscillating second-order [22], integrating plus time delay process [23], overdamped second-order processes [24], fourth-order blending process [25], coupled dual tanks [26], internal humidity of a greenhouse [27], rocket pitch angle [28], liquefied natural gas tank pressure [29], liquefied natural gas tank level [30], boiler temperature [31], boiler drum water level [32], furnace temperature [18], electro-hydraulic drive [33], rolling strip thickness [34], IME mold temperature [35], IMM barrel temperature [36], IMM cavity gate pressure [19], IMM mold cavity packing pressure [37], IMM ram velocity [38], full-electric IMM [39], Al-Jazari turbine [21], Banu Musa axial turbine power [40], Wind turbine speed [41], steam turbine speed [42], train velocity [43], car yaw rate [44], and car sideslip angle [45].
- The two elements of the PD-PI controller (PD and PI control modes) are set in cascade in the forward path of the block diagram of the barrel temperature control system just after the error detector.
- The transfer function of the PD-PI controller is given by [27]:

$$G_{PDPI}(s)=[K_dK_{pc2}s^2+(K_{pc1}K_{pc2}+K_dK_i)s+K_{pc1}K_i]/s \quad (4)$$

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 = integral gain of the PI-control mode

- The controller has four gain parameters which have to be tuned for optimum performance for reference track input and good performance for the purpose of disturbance rejection.
- The unit step time response of the control system for a reference input is obtained using the closed loop transfer function derived from the block diagram of the control system with zero disturbance, controller transfer function in Eq.4, process transfer function in Eq.1 and the '*step*' command of MATLAB [12].
- The PD-PI controller is tuned in the same way as the I-PD controller revealing the optimal gain parameters of the PD-PI controller as:

$K_{pc1} = 0.6692116$; $K_d = 0.010005$

$K_{pc2} = 1.4109364$; $K_i = 3.055815$ (5)

- The unit step time response of the control system for reference and disturbance inputs as generated by the MATLAB command '*step*' [12] using the PD-PI controller tuned gain parameters in Eq.5 and its transfer functions is shown in Fig.4.

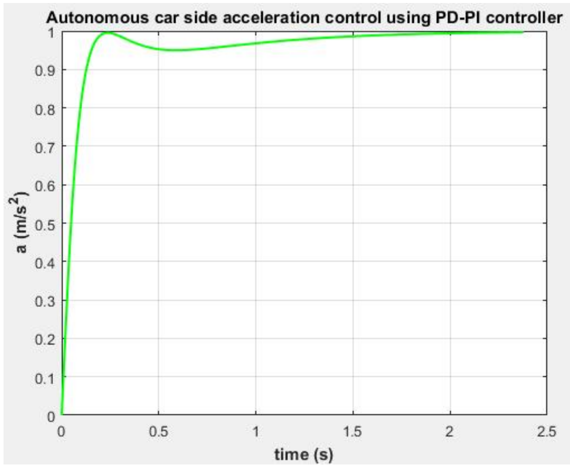


Fig.4 Lateral acceleration control using a PD-PI controller.

COMMENTS:

- Maximum overshoot: zero
- Settling time: 1.286 s
- Steady-state error: zero

V. LATERAL ACCELERATION CONTROL USING A 2DOF-2 CONTROLLER

- The 2DOF controller is one of the second generation controllers introduced by the author starting from 2014 to replace the first generation PID controllers. The author used different structures of 2DOF control to control a variety of industrial processes with bad dynamics such as: liquefied natural gas tank pressure control [29], liquefied natural gas level control [30], boost-glide rocket engine [50], BLDC motor control [51], highly oscillating second-order process [46], delayed double integrating processes [47], coupled dual tanks [25], furnace temperature [18], gas turbine speed [48], greenhouse temperature control [49], boiler temperature [31], boiler drum water level [32], electro-hydraulic drive [33], rolling strip thickness [34], IMM mold temperature [35], IMM cavity gate pressure [19], IMM packing pressure [37], IMM ram velocity [38], IMM barrel temperature [36], IMM full-electric machine [39], Al-Jazari turbine [21], Banu Musa axial turbine power [40], wind turbine speed [41], steam turbine speed [42], train velocity [43], car yaw rate [44] and car sideslip angle [45].

- The block diagram of a control system incorporating a 2DOF-structure 2 controller (denoted as 2DOF-2) proposed to control the autonomous car lateral acceleration is shown in Fig.5 [37].

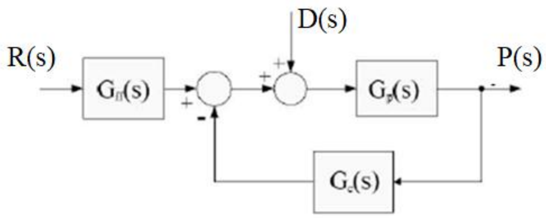


Fig.5 Block diagram of 2DOF-2 controlled process [37].

- The 2DOF-2 controller is composed of two elements: PI-control-mode of $G_{ff}(s)$ transfer function in a forward path receiving the reference input and a PID-control mode of $G_c(s)$ transfer function in the feedback path of the control system loop.
- The 2DOF-2 controller elements have the transfer functions:

$G_{ff}(s) = K_{pc1} + K_{d1}s$

And $G_c(s) = K_{pc2} + K_{d2}s$ (6)

- The 2DOF-2 controller has four gain parameters K_{pc1}, K_i, K_{pc2} and K_d to be tuned to adjust the performance of the closed-loop control system.
- The transfer functions of the closed-loop control system in Fig.5 are derived from the block diagram using Eqs.1 for the car lateral acceleration and 6 for the 2DOF-2 controller.
- The 2DOF-2 controller is tuned using the technique applied for the I-PD and PD-PI controllers propped in the above analysis. The results are as follows:

$K_{pc1} = 0.0658714$; $K_i = 0.3836779$

$K_{pc2} = 0.0701254$; $K_d = 0.0000339$ (7)

- The unit step time response of the control system for reference input tracking as generated by the MATLAB command '*step*' using the 2DOF-2 controller tuned gain parameters in Eq.7 and shown in Fig.6.

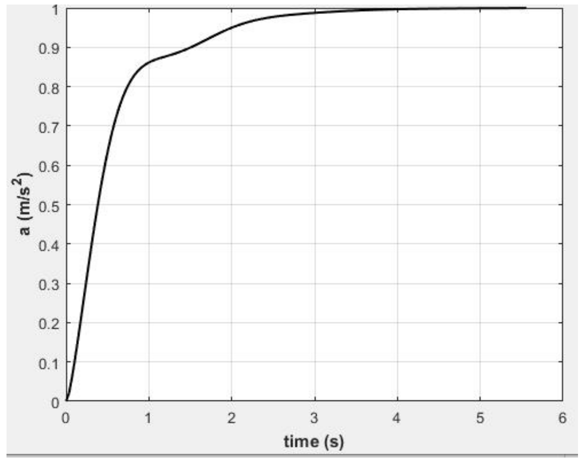


Fig.6 Lateral acceleration control using a 2DOF-2 controller.

COMMENTS:

- Maximum overshoot: zero
- Settling time: 2.6015 s
- Steady-state error: zero

VI. CAR STEERING ANGLE CONTROL USING A PID CONTROLLER

PID controller is one of the controllers of the PID first generation controllers. It still finds place in process control [33] .

- The transfer function of the conventional PID controller, $G_{PID}(s)$ is given by:

$G_{PID}(s)= K_{pc} + (K_i/s) + K_ds$ (8)

Where:

K_{pc} = proportional gain of the PID controller

K_i = integral gain of the PID controller

K_d = derivative gain of the PID controller

- The controller has three gain parameters which have to be tuned for optimum performance for reference tracking input.
- The unit step time response of the control system, c(t) for a reference input is obtained using the closed loop transfer function derived from the block diagram of the control system, controller transfer function in Eq.8, process transfer function in Eq.1 and the '*step*' command of MATLAB [12].
- The PID controller parameters are tuned using the same procedure used to tune the I-PD, PD-PI and 2DOF-2 controllers. The optimal gain parameters of the PID controller are obtained as:

$$K_{pc} = 0.498618 \;;\; K_i = 2.031287$$
$$K_d = 0.006118 \qquad (9)$$

- The unit step time response of the control system for reference input tracking using the tuned PID controller is shown in Fig.7.

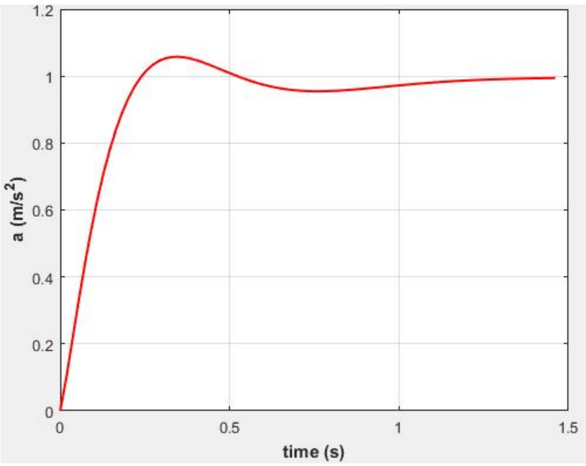


Fig.7 Lateral acceleration control using a PID controller.

COMMENTS:

- Maximum overshoot: 6.38 %
- Settling time: 1.09 s
- Steady-state error: zero

VII. COMPARISON OF TIME BASED CHARACTERISTICS

Graphical Comparison:

- The time-based characteristics of the control systems incorporating the proposed controllers proposed to control the autonomous car lateral acceleration are compared graphically through the step time response of 90 degrees (1.5708 rad) input (steering angle input) as depicted in Fig.8. A limit of the lateral car acceleration of 4.25 m/s2 is also drawn in the same graph [52].

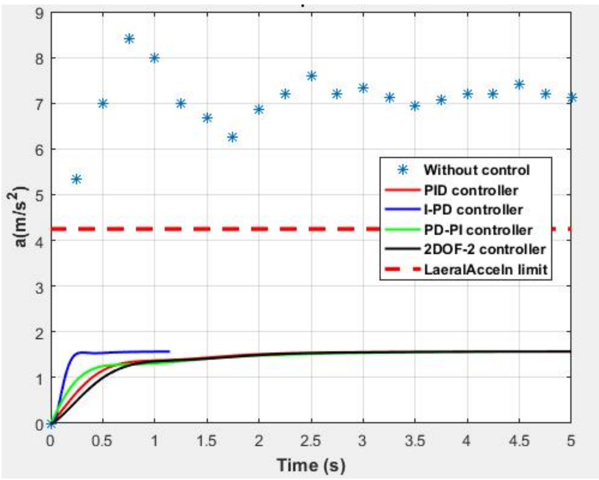


Fig.8 Lateral acceleration control using four controllers.

Numerical Comparison:

Numerical comparison for the time-based characteristics of the step time response for reference input tracking of the control system with the three proposed controllers is presented in Tables 1 with comparison with the application of a conventional PID controller used to control the same process.

TABLE 1
TIME-BASED CHARACTERISTICS FOR REFERENCE INPUT TRACKING OF AN AUTONOMOUS CAR LATERAL ACCELERATION CONTROL

Controller	Without control	I-PD	PD-PI	2DOF-2	PID
Maximum overshoot (%)	20.21	0	0	0	6.38
Settling time (s)	1.815	0.514	1.286	2.6015	1.09
Steady-state error (m/s^2)	-5.5622	0	0	0	0

VIII. CONCLUSIONS

- The research work presented in this research paper handled the tuning of I-PD, PD-PI, 2DOF-2 and PID controllers used to control an autonomous car lateral acceleration.
- The paper presented three controllers from the second generation of PID controllers and one controller from the first generation.
- The controlled process was a stable one having a transfer function fitted to an experimental data from a previous work and consisted of a simple zero, simple pole and a quadratic pole.
- The experimental date violated the limit of the lateral acceleration of the car (4.25 m/s^2).
- The four controllers were tuned using the MATLAB optimization toolbox with an ITAE performance index aiming at providing a good dynamic performance for the control system.
- All the proposed controllers succeeded to eliminate completely the steady-state error of the control system.
- All the proposed controllers succeeded to eliminate completely the maximum percentage overshoot of the control system compared with 6.38 % for the PID controller.
- All the proposed controllers provided lateral acceleration for step input tracking with input magnitude of 90 degrees (same input used with the experimental data).
- The I-PD controller could generate step time response having only 0.514 s settling time compared with 1.09 s for the PID controller.
- (Compared with 6.10 s for the PID controller).
- The I-PD controller was selected as the best controller regarding reference input tracking providing zero steady-state error, zero maximum overshoot and minimum settling time compared with the other controllers investigated in the present study.
- Regarding disturbance rejection associated with the car lateral acceleration, in a number of research papers published by the author, it was possible to achieve high level of disturbance rejection using input high pass filters.

REFERENCES

1. *C. Olsson, "Model complexity and coupling of longitudinal and lateral control in autonomous vehicles using model predictive control", Degree project Thesis in Automatic Control, Kth Royal Institute of Technology, School of Electrical Engineering, Stockholm, Sweden, 2015.*
2. *A. Elhefnawy, A. Sharaf, H. Ragheb and S. Hegazy, "Coordinated chassis based on vehicle lateral acceleration using fuzzy logic control", 17th International Conference on Aerospace Sciences & Aviation Technology, Paper: ASAT-17-097-GU, 17 pages, 11-13 April, 2017.*
3. *T. Novi, et al., "The influence of autonomous driving on passive vehicle dynamics", SAE Technical Paper 2018-01-0551, 8 pages, 2018.*
4. *A. Chokor, R. Talj, M. Doumiati and A. Charara, "Effect of roll motion control on vehicle lateral stability and rollover avoidance", American Control Conference, Denes, USA, pp.4868-4875, 2020.*
5. *S. A. Saruchi et al., "Lateral control with neural network based roll prediction model for motion sickness incidence minimization in autonomous vehicle", Journal of Engineering Science and Technology, vol.6, issue 2, pp.1630-1643, 2021.*
6. *A. Abdelaziem A. Ali and S. 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.*
7. *M. Moharrami and M. Mohammadi, " A new adaptive cruise control strategy considering road conditions", AUT Journal of Mechanical Engineering, vol.7, issue 4, pp.355-366, 2023.*
8. *M. Assi, M. Amer and B. Ozkan, "Adaptive model predictive control of yaw rate and lateral acceleration for an active steering vehicle based on tire stiffness estimation", Palestine Technical University Research Journal, vol.12, issue 2, pp.54-79, 2024.*
9. *A. Awouda and R. Mamat, "New PID tuning rule using ITAE criterion", International*

Journal of Engineering, vol.3, issue 6, pp.597-608, 2010.

10. *P. Venkataraman, "Applied optimization with MATLAB programming", John Wiley & Sons Inc., 2009.*
11. *MathWorks, "Correlation coefficients", https://www.mathworks.com/help/matlab/ref/corrcoef.html , 2024.*
12. *Mathworks, "Time-domain responses and plots", https://www.mathworks.com/help/control/ug/time-domain-responses-of-systems.html , 2024.*
13. *G. A. Hassaan, "Robustness of I-PD, PD-PI and PI-PD controllers used with second-order processes", International Journal of Scientific and Technology Research, vol.3, issue 10, pp.27-31, 2014 .*
14. *G. A. Hassaan, "Tuning of an I-PD controller used with a highly oscillating second-order process", International Journal of Mechanical Engineering and Technology, vol.5, issue 5, pp.115-121, 2014.*
15. *G. A. Hassaan, "Second generation of PID controllers for reference input tracking ", International Journal of Research in Engineering Management and Science, vol.1, issue 3, pp.25-30, 2021.*
16. *M. Ramadan and G. A. Hassaan, "Tuning of an I-PD controller for use with a third-order oscillating process", International Journal of Computer Techniques, vol.7, issue 4, pp.1-16, 2020.*
17. *G. A. Hassaan, "Controller tuning for disturbance rejection associated with delayed double integrating processes", International Journal of Science and Engineering, vol.6, issue 3, pp.1-7, 2020.*
18. *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, pp.1-10, 2024.*
19. *G. A. Hassaan, "Thermoplastics injection molding machine control, Part III: Cavity gate pressure control using I-PD, PD-PI, 2DOF-2 controllers and I-P compensator compared with a PID controller", International Journal of Research Publication and Reviews, vol.5, issue 5, pp.4387-4398, 2024.*
20. *G. A. Hassaan, "Thermoplastics injection molding machine control, Part IV: Mold packing pressure control using I-PD, PD-PI, 2DOF-2 controllers compared with an adaptive IMC controller", World Journal of Engineering Research and Technology, vol.10, issue 6, pp.94-114, 2024.*
21. *G. A. Hassaan, "Power turbine control, Part I: Al-Jazari turbine control using I-PD, PD-PI and 2DOF-3 controllers compared with a PI controller", International Journal of Research Publication and Reviews, vol.5, issue 7, pp.175-186, 2024.*
22. *G. A. Hassaan, "Tuning of a PD-PI controller used with a highly oscillating second-order process", International Journal of Scientific and Technology Research, vol.3, issue 7, pp.145-147, 2014.*
23. *G. A. Hassaan, "Tuning of a PD-PI controller used with an integrating plus time delay process", International Journal of Scientific and Technology Research, vol.3, issue 9, pp.309-313, 2014.*
24. *G. A. Hassaan, "Tuning of a PD-PI controller to control overdamped second-order processes", International Journal of Engineering and Research Publication and Reviews, vol.2, issue 12, pp.1042-1047, 2021.*
25. *G. A. Hassaan, "Tuning of controllers for reference input tracking of a fourth-order blending process", World Journal of Engineering Research and Technology, vol.8, issue 4, pp.177-199, 2022.*
26. *G. A. Hassaan, "Tuning of controllers for reference input tracking of coupled-dual liquid tanks", World Journal of Engineering Research and Technology, vol.8, issue 2, pp.86-101, 2022.*
27. *G. A. Hassaan, "Tuning of PD-PI and PI-PD controllers to control the internal humidity of a greenhouse", International Journal of Engineering Techniques, vol.9, issue 4, 9 pages, 2023.*
28. *G. A. Hassaan, "Control of a 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.*

29. G. A. Hassaan, "Liquefied natural gas tank pressure control using PID, PD-PI and 2DOF controllers", World Journal of Engineering Research and Technology, vol.10, issue 2, pp.18-33, 2024.
30. G. A. Hassaan, "Liquefied natural gas tank level control using PD-PI, I-PD and 2DOF controllers", World Journal of Engineering Research and Technology, vol.10, issue 1, pp.13-26, 2024
31. 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.
32. 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.
33. G. A. Hassaan, "Control of an electro-hydraulic drive using PD-PI PI-PD and 2DOF controllers compared with PID controller", International Journal of Engineering and Techniques, vol.10, issue 2, 10 pages, 2024.
34. G. A. Hassaan, "Rolling strip thickness control using PD-PI, Pi-PD and 2DOF controllers compared with single model adaptive Smith predictor", International Journal of Computer Techniques, vol.11, issue 2, 10 pages, 2024.
35. G. A. Hassaan, "Thermoplastics injection molding machine control, part I: Mold temperature control using I-PD compensator, PD-PI and 2DOF-2 controllers compared with a PID controller", World Journal of Engineering Research and Technology, vol.10, issue 5, pp.147-164, 2024.
36. 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.
37. 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.
38. 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.
39. 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.
40. 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.
41. 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.
42. 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.
43. G. A. Hassaan, "Autonomous vehicle control, Part III: Train velocity control with passenger comfort index using PD-PI, PI-PD and 2DOF controllers compared with a PID controller", International Journal of Computer Techniques, vol.11, issue 5, pp.1-12, 2024.
44. 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 Research and Technology, Accepted for publication, October 2024.
45. G. A. Hassaan, "Autonomous vehicle control, Part V: Car sideslip angle control using P-D, I-first order compensators and PD-PI and 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.

46. *G. A. Hassaan, "Tuning of a 2DOF controller for use with a highly oscillating second-order-like process", International Journal of Modern Trends in Engineering and Research, vol.2, issue 8, pp.292-298, 2015.*

47. *G. A. Hassaan, "Controller tuning for disturbance rejection associated with delayed double integrating process, Part V: 2DOF controller", International Journal of Engineering and Techniques, vol.1, issue 4, pp.26-31, 2015.*

48. *G. A. Hassaan, "Tuning of 2DOF controllers for the speed control of a gas turbine", International Journal of Engineering and Techniques, vol.8, issue 2, pp.35-44, 2022.*

49. *G. A. Hassaan, "Temperature control of a greenhouse using PD-PI, PI-PD and 2DOF controllers", International Journal of Engineering Inventions, vol.12, issue 9, pp.156-162, 2023.*

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

51. *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.*

52. *P. Bosetti, M. Lio and A. Saroldi, "On the human control of vehicles: an experimental study of acceleration", European Transportation Research Review, vol.6, pp.157-170, 2014.*

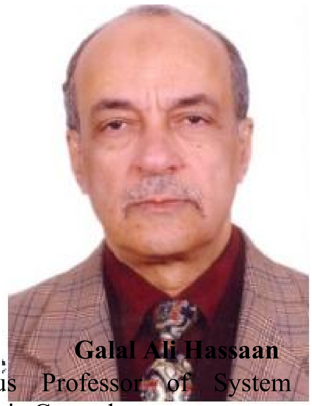
53. *Ceicdata , "Key information about Egypt motor vehicle production", https://www.ceicdata.com/en/indicator/egypt/motor-vehicle-production , 2021.*

54. *Wikipedia, "Automotive industry in Egypt", https://en.wikipedia.org/wiki/Automotive_industry_in_Egypt , 2024.*

DEDICATION
To
AUTOMOTIVE MANUFACTURERS IN EGYPT

- Annual production of automotive industry in Egypt is about 23700 vehicles in December 2020 [53].
- There are about 83 car manufacturers working in Egypt [54].
- Some of the automotive producers in Egypt are [54]: Al-Fotoah Car Assembly – Arab American Vehicles – Arab Organization for Industrialization – General Motors Egypt – Gabbour Group – Mercedes Egypt – Suzuki Egypt – Wagih Abaza Company – Speranza Motors – Saudi Group – Egyptian German Automotive Company – Nissan Motor Egypt.
- To all of car manufacturers in Egypt, I dedicate this research work hoping they can get benefit out of it and plan to produce autonomous cars in Egypt.

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.
- Chief Justice of the International Journal of Computer Techniques.
- Member of the Editorial Board of IJET.
- Reviewer in some international journals.
- Scholars interested in the authors publications can visit:

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