International Journal of Engineering and Techniques - Volume 9 Issue 4 Nov 2023

RESEARCH ARTICLE OPEN ACCESS

Tuning of PD-PI and PI-PD Controllers to Control the Internal Humidity of a Greenhouse

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Abstract:

This paper investigates the possibility of controlling a greenhouse inside humidity using an unstable humidity model. This is a big challenge because the proposed controller has to be able to depress the greenhouse disturbance beside a good performance for the reference input tracking step response. Two controllers from the 'second generation of PID controllers' are proposed for the humidity control: PD-PI and PI-PD controllers. The controllers are tuned using MATLAB optimization toolbox. The reference input and disturbance input tracking step time responses are analyzed for each of them and compared with those using a PID + first-order filter used in a previous work with the same process.

Keywords — **Greenhouse climate control, internal humidity control, PD-PI controller, PI-PD controller.**

I. INTRODUCTION

Any automatic control scheme depends on the use of a relevant mathematical model for the process under control. The inside humidity of the greenhouse is represented by nonlinear model which may be linearized to simplify the control scheme used. The selection of the linear model of the inside humidity of the greenhouse assigns the control techniques to be applied providing good performance and success in depression of the process disturbances. Let us start with literature survey for some of the research work in the field of modeling and control of the inside humidity of greenhouses.

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Rodriguez, Yebra, Berenguel and Dormido (2002) investigated the modeling of greenhouse climate for the purpose of simulating control and production optimization. They followed a procedure allowing the development and testing of sub-models before connecting them to generate a complete greenhouse model [1]. Lecomte et al. (2004) presented an study aiming at analyzing and developing a methodology for greenhouse control of humidity and electroconductivity and control the main climate parameters like air humidity and temperature. They used general transfer functions identified every week [2]. Bennis et al. (2008) investigated the dynamic problem of modelling and control of greenhouses inside climate using temperature and hygrometry variables. They stated that the two variables are very sensitive to the outside weather. They proposed the H_2 robust control strategy to control the greenhouse inside state [3]. Chen and Tang (2010) proposed a constraint optimal control approach to control greenhouse climate. They used Q-learning to search for optimal control strategy. They concluded that the experimental results showed that their approach was practical, effective and efficient [4]. Linker, Kacira and Arbel (2011) developed a climate control system using variable pressure fogging and variable speed fans. They used a robust control based on the Quantitative Feedback Theory (QFT). They applied partial decoupling between two control loops for air temperature and humidity [5]. Galvan et al. (2012) presented a review of different control strategies applied to manage greenhouse climate conditions. They presented the advantages and disadvantages of the developed control strategies to suggest a design methodology. Among their investigation was the conventional greenhouse climate control using the ON-OFF actuation and the PID controller. Besides the optimal control covering artificial intelligence, model predictive control and expert systems [6]. Gurban and Gheorghe (2012) presented an equivalent greenhouse climate control based on feedback-feedforward compensation technique for linearization, decoupling and disturbances compensation of the greenhouse complex model. They used an equivalent model reduced to an integral plus dead-time decoupled greenhouse variables. They used and tuned a PID controller with a first-order filter having a unit gain to control the integral plus dead-time model for temperature and humidity control. They applied nine tuning techniques resulted in humidity unit step time response performance having maximum percentage overshoot between 7.5 to 29.2 % and settling time between 478 and 971 s [7].

Hirasawa et al. (2014) analysed the effect of control of ventilation, sprinkler water and solar radiation shielding on changes of temperature and humidity in a greenhouse under various desert area conditions. They concluded that the relative humidity in the greenhouse was maximum when the shielding ratio was 0.4 decreased when the ventilation was larger than 1 m^3/s [8]. Ali, Aridhi and Mami (2015) presented a dynamic model of a greenhouse to predict the air temperature and relative humidity using MATLAB/Simulink environment. Their simulation results showed the variation of air temperature and humidity inside the greenhouse with wither conditions. They presented graphically the variation of the relative humidity outside and inside the greenhouse during four days [9].

Manonmani, Yhyagorajan, Sutha and Gyathri (2016) developed decoupled linear models using the feedback-feedforward linearization technique. They designed a PI controller using Internal Model Control (IMC), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for minimum Integral Square Error (ISE). The Pi controlled humidity had maximum overshoot between 2.24 and 3.66 % and settling time between 27 and 30 s [10]. Cruz et al. (2018) summarized the main developments of dynamic models of the greenhouse climate. They described the type of equations used (differential, difference, transfer functions). They stated that models with few states were more useful for control and optimization purposes. They investigated greenhouse climate models for PID control and robust feedback and feedforward control [11]. Fikir (2019) in his master thesis applied a model-predictive control to regulate both greenhouse temperature and humidity. He used a fuzzy modelling strategy using Takagi-Sugeno fuzzy modelling to model the greenhouse and update the models parameters. He linearized the nonlinear models using a fuzzy-linearization algorithm. He investigated the use of a Model Predictive Control (MPC) algorithm [12]. Riahi, Vergura, Mezghani and Mami (2020) proposed a simulated dynamic model for experimental validation and designed a fuzzy controller to control the greenhouse indoor climate. They modeled a photovoltaic generator to feed the asynchronous motor with a vector control optimized by fuzzy logic driving a variable speed fan [13].

Khalaf and Kim (2021) focused their study on controlling air temperature and relative humidity inside a 2x2x1.5 m greenhouse prototype. They controlled the air temperature to a reference value of 27°C and the relative humidity to a reference value of 82%. They used switching ON/OFF procedure for heater, humidifier, dehumidifier and air fan using Arduino Uno MC and relays [14]. Ayala, Velandia and Lara (2022) presented a review article with the objective of determining relationships in fuzzy inference system used for modeling, prediction and control of the humidity in greenhouses. They concluded that the development of models based on fuzzy inference systems integrated with optimization, fuzzy clustering, model based predictive model could guarantee high level of precision [15]. Ma, He, Jin and Hou (2023) presented a simple and fast optimal predictive tracking control method. They established a multi-degree of freedom discrete time state space model with tracking errors and applied the gradient descent theory with actual constraints. They used rolling optimization and iterative methods to assign the optimal control rate to minimize optimization function. They concluded that model predictive control with optimization constraints achieved more accurate prediction and tracking control of the greenhouse indoor variables [16].

II. THE ABSOLUTE HUMIDITY MODEL

There are a number of linearized and decoupled dynamic models available in the literature for the greenhouse inside air humidity. The complexity and efficiency of the adopted control strategy depend on the shape of the humidity dynamic model. The requirements from any control scheme are to provide excellent performance for both reference input and disturbance tracking.

One of the available linear model in the form of a transfer function for the greenhouse humidity was provided by Gurban and Andreescu composing of an integral and a dead-time in the form [7]:

$$G_p(s) = K\,e^{-Tds} / s \qquad (1)$$

Where:

K = process gain.

T_d = dead-time of the greenhouse.

According to reference [7], the greenhouse humidity parameters of the model in Eq.1 are:

$$K = 1 \text{ and } Td = 30 \text{ s} \qquad (2)$$

To ease the analysis with the presence of dead-time, the first-order Pade approximation is used to replace the dead-time term in Eq.1. The fist-order Pade approximation is given by [17]:

$$e^{-Tds} = (1-0.5T_d s)/(1+0.5T_d s) \qquad (3)$$

Combining Eqs.1, 2 and 3 gives the greenhouse humidity transfer function as:

$$G_p(s) = (-15s + 1)/(15s^2 + s) \qquad (4)$$

The dynamic response characteristics of the humidity process are investigated through its unit step response generated by the 'step' command of MATLAB and shown in Fig.1 [18].

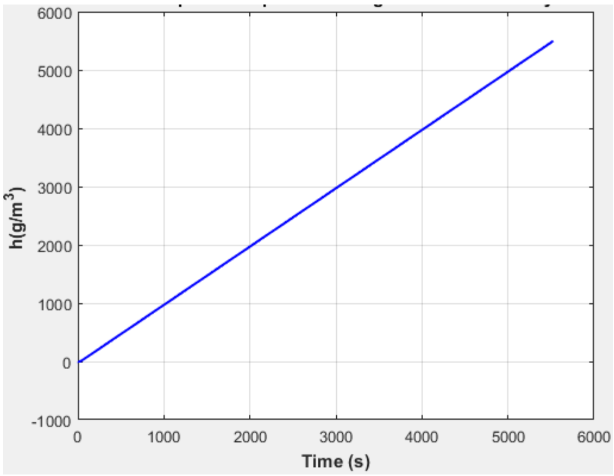


Fig.1 Unit step response of the greenhouse humidity.

Fig.1 reveals the following facts:

- The used mathematical linear model for the greenhouse humidity reveals an unstable process.
- This puts more challenges for the selected controllers to control it with good performance.

III. HUMIDITY CONTROL USING A PIDF CONTROLLER

- This controlling technique was used in reference [7] to control the humidity process defined by Eq.4.
- The PIDF controller has four parameters: K_{pc}, T_i, T_d and T_f appearing in the PIDF transfer function G_{PIDF} (s) given in Eq.5 [7].

$$G_{PIDF}(s) = K_{pc}[1+(1/T_i s)+T_d s]/(T_f s+1) \qquad (5)$$

Where:

K_{pc} = proportional gain.

T_i = integral time constant of the PID controller.

T_d = derivative time constant of the PID controller.

T_f = time constant of the filter.

- The PIDF controller was tuned in reference [7] for the tracking input step response giving the following controller parameters [7]:

$$K_{pc} = 0.012, \quad T_i = 279 \text{ s}$$
$$T_d = 26.8 \text{ s}, \quad T_f = 12.2 \text{ s} \qquad (6)$$

- The transfer of the control loop comprising the PIDF controller [with $G_{PIDF}(s)$] and greenhouse with humidity model [with $G_p(s)$] in series in the forward path of the control loop for reference input tracking, $M_{R1}(s)$ is given by:

$$M_{R1}(s) = G_{PIDF}(s)\, G_p(s)/[1+G_{PIDF}(s)G_p(s)] \qquad (7)$$

- With disturbance D(s) acting in the input of the greenhouse model, the transfer function for disturbance input tracking, $M_{D1}(s)$ is given by:

$$M_{D1}(s) = G_p(s)/[1+G_p(s)G_{PIDF}(s)] \qquad (8)$$

- Using Eqs.4 to 8, the unit step time response of the greenhouse humidity using the PIDF controller for both reference input and disturbance input tracking is shown in Fig.2

as generated by the MATLAB command ‘step’ [18]. Comments:

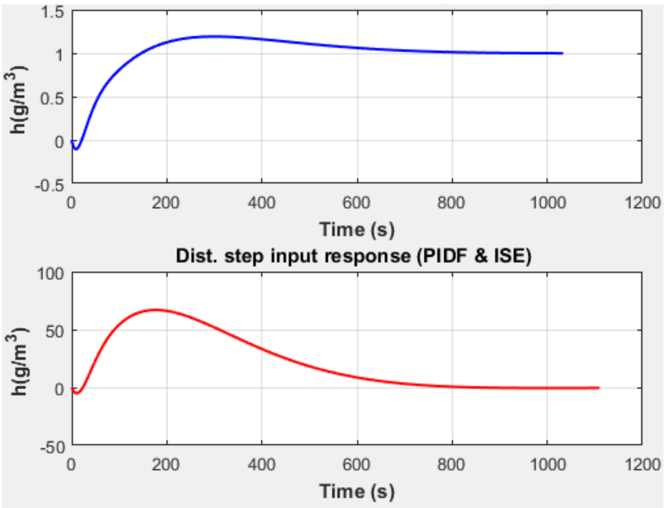
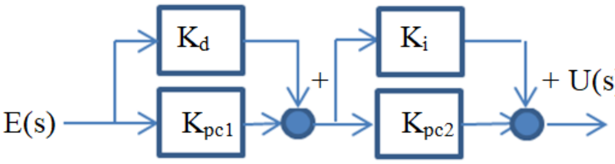


Fig.2 Greenhouse humidity control using PIDF controller.

- For reference input tracking using the PIDF controller:
  - Maximum percentage overshoot: 19 %.
  - Settling time: 745 s.
  - Steady-state error: 0
- For disturbance input tracking:
  - Maximum humidity time response: 66.8 g/m^3.
  - Time of maximum time response: 177 s.
  - Settling time: 800 s.

IV. HUMIDITY CONTROL USING A PD-PI CONTROLLER

- The PD-PI controller is one of the controllers belonging to the ‘*second generation of PID controllers*’ introduced by the author in 2014 to get rid of the deficiencies of PID controllers.
- The author used and tuned a PD-PI controller to control a highly oscillating second-order process [19], first-order delayed processes [20], an integral plus time delay process [21], a third-order process [22] and a greenhouse temperature control process [23].
- The block diagram of the PD-PI controller as used by the author in the above applications is shown in Fig.3 [19, 24].
- The PD-PI controller consists of two sub-controllers: PD mode and PI modes structured in cascade as illustrated in Fig.3.
- The PD-PI controller has four parameters: K_{pc1}, K_d, K_{pc2} and K_i appearing in the PD-PI transfer function G_{PDPI} (s) given in Eq.9.



PD-PI controller structure.

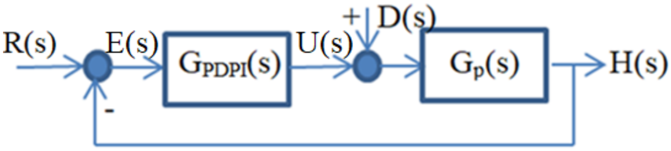


Fig.3 Block diagram of a PD-PI controlled process with disturbance [19].

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

Where:

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

K_d = derivative gain of the PD mode.

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

K_i = integral gain of the PI mode.

- The transfer function of the closed loop control system for the reference input (with D(s) set to zero in Fig.3) is given by:

$$M_{R2}(s) = G_{PDPI}(s)\, G_p(s)/ [1+G_{PDPI}(s)G_p(s)] \quad (10)$$

- Equations 4, 9 and 10 are used in the tuning operation of the PD-PI controller to adjust the four controller parameters for minimum ISTSE performance index using the MATLAB optimization toolbox [25].
- The tuned PD-PI controller parameters are:

$$K_{pc1} = 12.74441;\ K_d = 11.80623$$
$$K_{pc2} = 10.83992;\ K_i = 12.06973 \quad (11)$$

- The transfer function of the control system for disturbance input tracking is given by Eq.8 with $G_{PDPI}(s)$ replacing $G_{PIDF}(s)$.

- The unit step time response of the control system for both reference input and disturbance input tracking is given in Fig.4. Comments:

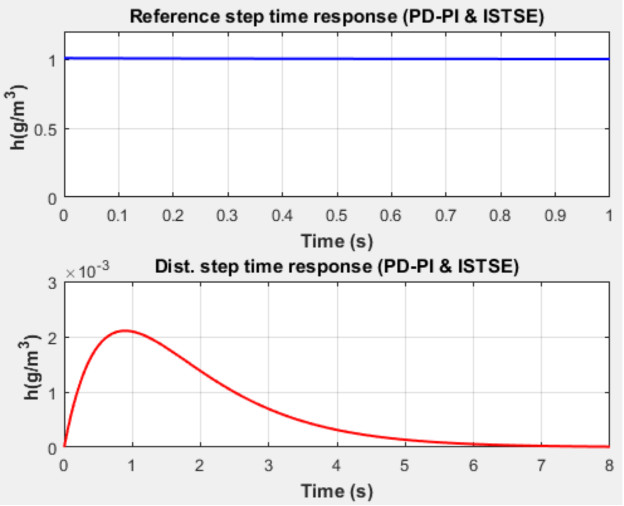


Fig.4 Greenhouse humidity control using PDPI controller.

- For reference input tracking using the PD-PI controller:
- Maximum percentage overshoot: 0.781 %.
- Settling time: 0
- Steady-state error: 0
- The reference input tracking step time response is approximately a perfect step using the PD-PI controller.
- For disturbance input tracking:
  - Maximum humidity unit step time response: 0.0021 g/m^3.
  - Time of maximum time response: 0.8 s.
  - Settling time: 8 s.
  - The disturbance input tracking step time response exhibited maximum value less than 0.0022 g/m^3 in less than 1 second and settled to zero within only 8 seconds which is a great achievement using the PD-PI controller.

V. HUMIDITY CONTROL USING A PI-PD CONTROLLER

- The PI-PD controller is one of the controllers belonging to the '*second generation of PID controllers*' introduced by the author in 2014 to get rid of the deficiencies of PID controllers.
- The author used and tuned a PI-PD controller to control a highly oscillating second-order process [26], delayed double integrating process [27], a third-order process [28] and a greenhouse temperature control process [23].
- The block diagram of the PI-PD controller as used by the author in the above applications is shown in Fig.5 [23].
- The PI-PD controller consists of two sub-controllers: PI mode and PI modes structured as shown Fig.5.
- The PI-PD controller has four parameters: K_{pc1}, K_i, K_{pc2} and K_d.
- The block diagram of the control system with PI-PD controller comprises two loops: an internal loop with the controlled process in its forward path and a PD control mode in its feedback path and an external loop comprising a PI control mode and the internal loop.
- Using block diagram algebra and the equations for $G_{pi}(s)$, $G_{pd}(s)$ and $G_p(s)$, the transfer functions for reference input and disturbance input can be deduced.

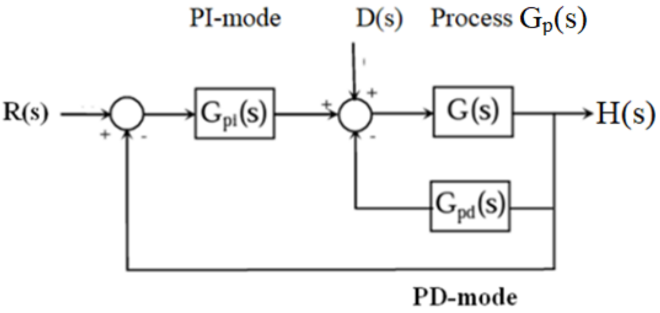


Fig.5 Block diagram of a PI-PD controlled process with disturbance [23].

- The PI-PD controller parameters are tuned using the MATLAB optimization toolbox for an ITAE performance index. The tuning results are as follows:

  $K_{pc1} = 25.00809$; $K_i = 9.783599$

  $K_{pc2} = 1.466987$; $K_d = 3.810877$ (12)
- The unit step time response of the control system for both reference input and disturbance input tracking is given in Fig.6.

- Comments:
- ➢ For reference input tracking using the PI-PD controller:
- ➢ Maximum percentage overshoot: 0
  Settling time: 0.462 s
- ➢ Steady-state error: 0

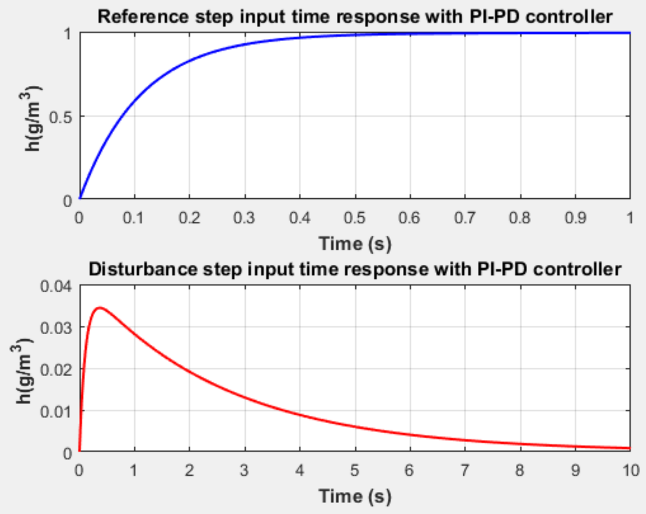


Fig.6 Greenhouse humidity control using PI-PD controller.

- ➢ For disturbance input tracking:
  - Maximum humidity unit step time response: 0.0344 g/m^3.
  - Time of maximum time response: 0.36 s.
  - Settling time: 12 s.
  - The disturbance input tracking step time response exhibited maximum value less than 0.035 g/m^3 in less than 0.4 second and settled to zero within only 12 seconds which is also a great achievement using the PI-PD controller.

VI. COMPARISON OF THE HUMIDITE CONTROL PERFORMANCE USING PIDF, PD-PI AND PI-PD CONTROLLERS

The comparison is presented in graphical and numerical forms for better comparison of the three controllers handled in the paper as follows:

- The graphical comparison for unit step reference input using PIDF, PD-PI and PI-PD controllers is shown in Fig.7.
- The graphical comparison for unit step disturbance input using PIDF, PD-PI and PI-PD controllers is shown in Fig.8.

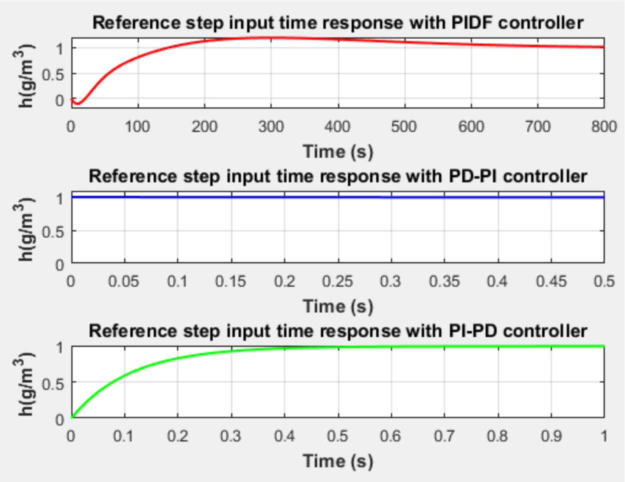


Fig.7 Graphical comparison for reference tracking input.

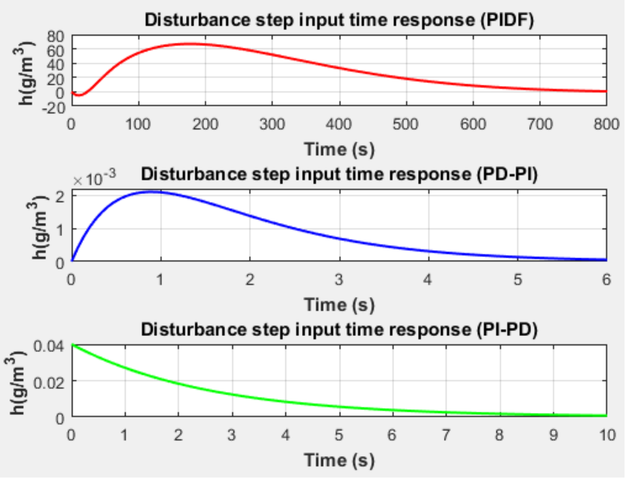


Fig.8 Graphical comparison for disturbance tracking input.

- Quantitative comparison for the characteristics of the greenhouse control system with reference input is presented in Table 1.

- Quantitative comparison for the characteristics of the greenhouse control system with disturbance input is presented in Table 2.

Table 1: Quantitative comparison for reference input greenhouse characteristics for humidity control.

Controller	Maximum percentage overshoot (%)	Settling time (s)	Controller generation
PIDF	19.13	746	First
PD-PI	0.781	0	Second
PI-PD	0	0.462	Second

Table 2: Quantitative comparison for disturbance input greenhouse characteristics for humidity control.

Controller	Maximum step time response (g/m^3)	Settling time (s)	Controller generation
PIDF	66.88	800	First
PD-PI	0.0021	8	Second
PI-PD	0.034	12	Second

VII. CONCLUSIONS

- The research work presented in the present paper was about controlling an unstable greenhouse humidity process.
- It proposed two controllers from '*the second generation of PID controllers*' introduced by the author in 2014. The PD-PI and PI-PD controllers.
- The two controllers were tuned using the MATLAB optimization toolbox with an appropriate performance index aiming at providing a stable control system and good dynamic performance.
- The performance of the control system incorporating the proposed controller and the unstable process was compared with this of a control system using a PID controller with filter from previous research work.
- The PD-PI controller could generate reference input and disturbance input tracking step time response having:
  - ➢ For reference input tracking:
    - ✚ 0.781 % maximum overshoot compared with 19 % when using a PIDF controller.
    - ✚ Almost zero settling time compared with 745 s when using a PIDF controller.
  - ➢ For disturbance input tracking:
    - ✚ 0.0021 g/m^3 maximum humidity at 0.8 s compared with 66.8 g/m^3 at 177 s when using a PIDF controller.
    - ✚ 8 s settling time compared with 800 s when using a PIDF controller.
- The PI-PD controller could generate reference input and disturbance input tracking step time response having:
  - ➢ For reference input tracking:
    - ✚ Zero maximum overshoot compared with 19 % when using a PIDF controller.
    - ✚ 0.462 s settling time compared with 745 s when using a PIDF controller.
  - ➢ For disturbance input tracking:
    - ✚ 0.0344 g/m^3 maximum humidity at 0.36 s compared with 66.8 g/m^3 at 177 s when using a PIDF controller.
    - ✚ 12 s settling time compared with 800 s when using a PIDF controller.
- The performance of the control system using the PIDF, PD-PI and PI-PD controllers were compared graphically and numerically through the characteristics of the control system performance.

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DEDICATION

I dedicate this research to my lifelong friend, Major General Saeed Abdullah Eid, one of the heroes of the 1973 war, whose friendship and encouragement I am still happy with. Thanks dear friend for all what you have done for our beloved Egypt and wishing you good health.

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 300 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.
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