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Performance Enhancement of PID Tuning of DC Servomotor using Metaheuristic Algorithm

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Abstract

The use of DC servomotor in automated systems is common nowadays in various applications. Specifically, DC servomotors have played a vital role in the development of surface mount technology (SMT) placement machines that have the ability to quickly place components onto the printed circuit boards (PCBs). The design of controllers for DC servomotors has increasingly become an interesting area for researchers from all over the world. Although the Proportional-Integral-Derivative (PID) controller is regarded as the workhorse of the control industry and it is used for DC servomotor, one of its main short-comings is that there is no efficient tuning method. This paper discusses the development of an algorithm that improves the performance of PID tuning based on Metaheuristic Algorithm; particularly, the Inertia Weight Particle Swarm Optimization (iw-PSO) algorithm. The research findings show the effectiveness of the PSO algorithm compared with the conventional PID controller. Overall, the iw-PSO-PID successfully eliminated the overshoot and at the same time produced faster response. Furthermore, it was able to control the convergence by indicating smaller value of MSE.

Index Terms: PID Tuning, DC Servomotor, Metaheuristic Algorithm, Inertia Weight Particle Swarm Optimization

1. INTRODCUTION

Automated systems are common place in daily life where they can be found in almost any electronic devices and appliances that are used daily, starting from air conditioning systems, automatic doors, and automotive cruise control systems to more advanced technologies such as robotic arms, production lines and thousands of industrial and scientific applications [1]. Any automated system should have an actuator module that makes the system to actually perform its function. The most common actuator used to perform this task is the DC servomotor.

The global servomotors and drives market shipments are expected to reach around 17.2 million units, and revenues are likely to reach around $10.43 billion by 2018. Lighter machines, reduction in size, increased speed, and high torque represent technical growth [2]. Historically, DC servomotors also played a vital role in the development of surface mount technology (SMT) placement machines that have the ability to quickly place components onto the printed circuit boards (PCBs). The Semiconductor Industry Association (SIA) has reported that to achieve excellent pitch devices, high accuracy placement machines have to be used with high-resolution vision systems and high throughput capabilities. Since DC servomotors are extensively used in the semiconductor industry and other industries, the design of controllers for these systems has been an interesting area for researchers from all over the world [3].

The use of control techniques has been extensive in DC servomotor based applications, and the Proportional-Integral-Derivative (PID) controller is regarded as the workhorse of the control industry [4]. In spite of its widespread use, one of its main short-comings is that there is no efficient tuning method for this conventional PID (*c*-PID) controller to adapt to different situations [5-7]. This paper discusses the development of an algorithm that can improve the performance of PID tuning based on Metaheuristic Algorithm; particularly, the Inertia Weight Particle Swarm Optimization (*iw*-PSO) algorithm.

2. LITERATURE REVIEW

There has been numerous reported works on the use of various techniques for motor control and other general applications [8-11]. Particle swarm optimization (PSO) is an evolutionary meta-heuristic algorithm based on the collective behavior emerging from the interaction of the different search threads that has proved effective in solving combinatorial optimization problems [10]. In [12], the use of GA and PSO on DC servomotor outperformed Z-N method; in [13] the modified PSO on ultrasonic DC motor enhanced the performance of PSO in term of convergence speed and position accuracy of ultrasonic motor; in [14], the application of PSO on DC motor yielded less overshoot compared to the traditional method; in [15], the use of PDPSO on linear brushless DC Motor gave better results; in [16], the use of PSO-PID on DC motor improved system performance. Similarly, in [17], the use of PSO-PID and PSO-Fuzzy on DC motor produced better speed control; and in [18], the use of PSO on AC servo motor produced good results. It can be deduced that various techniques are able to produce better results compared to conventional controllers in the motor applications. This provides justification for the research that was carried out using PSO.

3. MATERIALS AND METHODS

3.1 DC Servomotor

The general Transfer Function of a DC servomotor is given in Equation (1).

$$G(s) = \frac{\omega(s)}{v(s)} = \frac{K_m}{[(R_a + L_a s)(Js + b) + K^2]} \quad (1)$$

where, it is assumed that $K = \sqrt{K_m K_b}$.

Based on the the following parameters; $R_a = 1\,\Omega$, $L_a = 0.5\,H$, $J = 0.01\ kgm^2$, $b = 0.00003\ Nms/rad$, $K_m = 0.023$ and $K_b = 0.023$, the final transfer function, $G(s)$ of the DC servmotor is given in Equation (2),

$$G(s) = \frac{0.023}{(1+0.5s)(0.01s+(3\times10^{-5}))+(5.29\times10^{-4})} \quad (2)$$

3.2 PSO Algorithm

For the PSO algorithm, in terms of measurement metrics, Mean Squared Error (*MSE*) is utilized to evaluate the dynamical behavior and convergence characteristic. Moreover *MSE* indicates the convergence of swarm. The smallest value of *MSE* will be desirable and indicating the control of convergence of swarm. Therefore MSE is significant in this research in order to find the optimal solution. The formula for *MSE* is shown in the following equation [19, 20]:

$$mean(\bar{x}) = \frac{\sum_{i=1}^{p} w_i}{p} \quad (3)$$

$$MSE = \frac{1}{p}\sum_{i=1}^{p}(w_i - \bar{x})^2 \quad (4)$$

where,

MSE is mean squared error
w_i is particle position
p population size,
$\bar{x}$ is mean value.

The *iw*-PSO-PID Algorithm is implemented based on the following steps:

Step	Desription
1	The DC servomotor transfer function is derived based on the datasheet of chosen motor by obtaining the physical parameters using the SI units.
2	Simulation is carried out in MATLAB both for open loop and closed-loop transfer functions based on the conventional PID (*c*-PID) controller.
3	Transfer function is then converted into time domain using Inverse Laplace Transform. Edit Y_Model according to equation that has been calculated in time domain, and then, the program is developed in C++ compiler (Dev C++).
4	The program is then compiled by varying the parameters, such as no of particle, acceleration coefficient (*c*1and *c*2), and random number (*r*1 and *r*2)
5	The program would continue for a few iterations until it reaches the lowest *MSE*. Then, the best values of *Kp*, *Ki*, and *Kd* are produced.
6	To determine other control performance parameters like rise time, settling time, overshoot and steady state error, three controller parameters are simulated in MATLAB.

The simulation was carried out for the conventional PID (*c*-PID) using Matlab and *iw*-PSO-PID was implmented in C++.

4. RESULTS AND DISCUSSION

4.1 Conventional PID (*c*-PID) Tuning Method

All results based on the conventional PID (*c*-PID) tuning method for the plant are shown in Figures 1 to 3 and Table 1 respectiely.

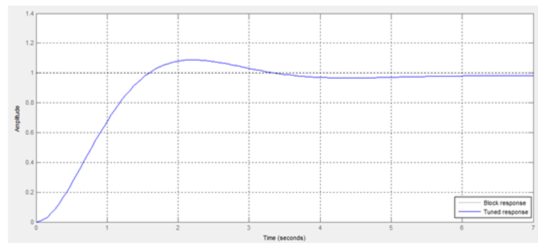

Fig-1: *c*-PI Controller for the Plant

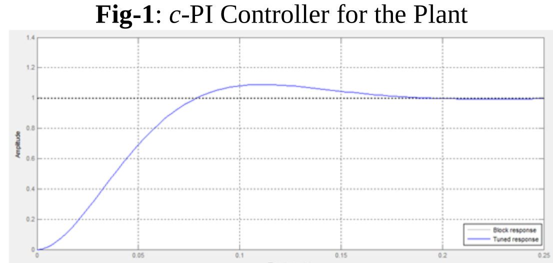

Fig-2: *c*-PD Controller for the Plant

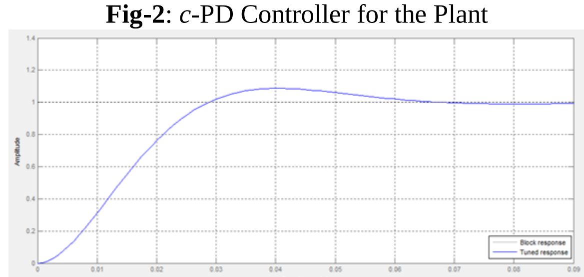

Fig-3: *c*-PID Controller for the Plant

Table-1: Summary of Results

	Control Gains			System Performance			
	K_p	K_d	K_i	t_s	t_r	*OS % (Mp)*	*MSE*
P	1.3695	n/a	n/a	3.32	0.577	25.8	0.004055
I	n/a	n/a	0.0008874	131	41.3	8.61	0.9318
PD	13.1124	6.0279	n/a	0.17	0.0526	9.06	0.002857
PI	0.6401	n/a	0.0142	6.02	1.07	8.79	0.05886
PID	31.3727	17.228	12.6789	0.0601	0.0192	8.66	0.001042

It can be seen from Table 1 that the best controller for the plant is PID with lowest *MSE* of 0.001042, *%OS (Mp)* of 8.66, settiling time (t_s) of 0.0601 and rise time (t_r) of 0.0192. This was achieved with gain values of *Kp*=31.3727, *Kd*=17.228 and *Ki*=12.6789.

4.2 *iw*-PSO-PID Controller

All results based on the *iw*-PSO-PID tuning method for the plant are shown in Figure 4 and Table 2 respectiely.

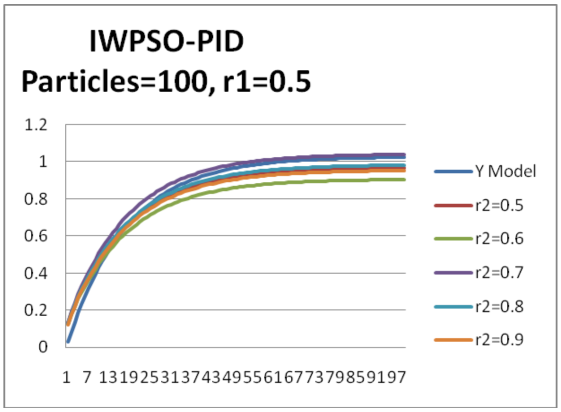

Fig-4: *iw*-PSO-PID Controller for the Plant

Table-2: Summary of *iw*-PSO-PID Results for the Plant

K_p	1.01447	0.957512	0.950494
K_i	1.3602e-6	1.31198e-6	1.33301e-6
K_d	1.98022	kd: 1.96239	2.04955
Particles	100	100	100
r1	0.5	0.5	0.5
r2	0.7	0.8	0.9
Iterations	11	14	14
t_s	0.050	0.083	0.085
t_r	0.030	0.042	0.040
OS% (Mp)	0	0	0
MSE	0.161612	0.164599	0.205675

It can be noted from Table 2 that the best *iw*-PSO-PID controller for the plant is with lowest *MSE* of 0.161612, no *%OS (Mp)*, settiling time (t_s) of 0.050 and rise time (t_r) of 0.030. This was achieved with gain values of *Kp*=1.01447, *Kd*=1.98022 and *Ki*=1.3602e-6 through 11 iterations with 100 particles, r1=0.5 and r2=0.7. Overall, the results show the influence of different parameters such as particle size (*N*), *c1, c2, r1 and r2* on the system performance in terms of controller gain (K_p, K_d, K_i) and system performance (t_s , t_r , *OS% (Mp), MSE*).

4.3 Comparative Analysis

A comparative analysis of the results based on the controllers, *c*-PID and *iw*-PSO-PID is carried out by presenting the results of *c*-PID and *iw*-PSO-PID for the plant in terms of controller gain (K_p, K_d, K_i) and system performance (t_s , t_r , *OS% (Mp), MSE*) in Table 3.

Table-3: Results of *c*-PID and *iw*-PSO-PID for the plant

	Control Gains			System Performance				Remarks
	K_p	K_d	K_i	t_s	t_r	*OS % (Mp)*	*MSE*	
c-PID	31.3727	17.228	12.6789	0.0601	0.0192	8.66	0.001042	
iw-PSO-PID	1.01447	1.98022	1.3602e-6	0.050	0.030	0	0.161612	Particles =110, r1=05, r2=0.7

As a whole, it can be seen from Table 3 that the *iw*-PSO-PID controller perform better than *c*-PID alone in terms *MSE* with 160 fold improvement, 8 fold improvement in *%OS (Mp)* , 10 fold improvement in settling time (t_s), 3 fold improvement in rise time (t_r), 30 fold for K_p, 8 fold for K_d and 10 fold for K_i . It can be seen that the *iw*-PSO-PID controller provide considerable improvements compared with *c*-PID. The research findings show the effectiveness of the PSO algorithms compared with the conventional PID controller. More importantly, this research demonstrates the ability to optimize PID parameters for a DC servomotor, an application that is increasingly being researched.

CONCLUSION

This paper has discussed the results of the controller design of DC servomotor. The paper presented the findings of conventional controller, *c*-PID and this was followed by the *iw*-PSO-PID controller. Then, a comparative analysis of the results was discussed. It can be concluded that the *iw*-PSO-PID controller produce better results in terms of system performance as compared to the *c*-PID. Overall, the *iw*-PSO-PID successfully eliminated the overshoot and at the same time produced faster response. Furthermore, it was able to control the convergence by indicating smaller value of *MSE*.

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REFERENCES:

i. Rashmi Ranjan Maharana and Ravi Sindal, DC Servomotor Speed Control based on UDP Communication, International Journal of Contemporary Technology & management, IJCTM Volume II , Issue V , June 2013.

ii. Research and Markets, Servo Motor & Drives Market: 2013 – 2018, 9 August, 2013, PRNewswire, Dublin, downloaded on 13th Dec 2013, http://www.researchandmarkets.com/research/7vbnts/servo_motor

iii. Yahia Makableh, Efficient Control Of Dc Servomotor Systems Using Backpropagation Neural Networks, Msc Thesis, The University Of Jordan, Jordan, 2009

iv. Pillay N. and Govender P., "A Particle Swarm Optimization Approach for Model Independent Tuning of PID Control Loop", IEEE Africon 2007, IEEE Catalog: 04CH37590C, ISBN: 0-7803-8606-X, 2007

v. Sekara, Tomislav B. &Mataus˘ek, Miroslav R. (2009). Optimization of PID controller based on maximization of the proportional gain under constraints on robustness and sensitivity to measurement noise, IEEE Trans. Autom. Control, Vol. 54(1): 184-189

vi. Toscano, R. &Lyonnet, P. (2009). Robust PID controller tuning based on the heuristic Kalman algorithm, Automatica, Vol. 45: 2099-2106

vii. Li, Y. &Xu, Q. (2010). Adaptive sliding mode control with perturbation estimation and PID sliding surface for motion tracking of a piezo-driven micromanipulator, IEEE Trans. Control Syst. Technol., Vol. 18(4): 798-810

viii. Raal Mandour and Elamvazuthi, I., Optimization of Maximum Power Point Tracking (MPPT) of Photovoltaic System using Artificial Intelligence (AI) Algorithms, Journal of Emerging Trends in Computing and Information Sciences, Vol. 4, No. 8 Aug 2013, ISSN 2079-8407.

ix. T Ganesan, I Elamvazuthi, KZ Ku Shaari, P Vasant, Swarm intelligence and gravitational search algorithm for multi-objective optimization of synthesis gas production, Applied Energy 103, 368-374

x. Ganesan, T., Vasant, P., Elamvazuthi, I., Hybrid Neuro-Swarm Optimization Approach for Design of Distributed Generation Power Systems, Neural Computing and Applications 23 (1) , pp. 105-117, 2013

xi. A M Parimi, I Elamvazuthi, N Saad, Improvement of Power System Stability with Fuzzy Logic Based IPFC, International Review of Electrical Engineering 5 (3)

xii. Sulochana Wadhwani and Veena Verma, Evolutionary Computation Techniques based Optimal PID Controller Tuning, International Journal of Engineering Trends and Technology (IJETT) - Volume4 Issue6- June 2013, pp. 2529-2534

xiii. Djoewahir Alrijadjisl, Kanya Tanakal, Shota Nakashimal, A Hybrid Strategy for Improving PSO and ItsApplication for Self-Tuning PID Controller on Position Control of Ultrasonic Motor, 2013 International Conference of Information and Communication Technology (ICoICT)

xiv. Mahmud IwanSolihin, Lee Fook Tack and Moey Leap Kean (2011) Tuning of PID Controller Using Particle SwarmOptimization (PSO) Proceeding of the International Conference on Advanced Science,Engineering and Information Technology 2011

xv. Verma, H.K., & Jain C. (2011). A Performance-Dependent PSO based Optimization of PID Controller for DC Motor. International Conference on Electrical Energy System

xvi. Payakkawan, P., Klomkarn, K., &Sooraksa, P. (2009). Dual-line PID Controller based on PSO for Speed Control of DC Motor. ISCIT

xvii. Allaoua, B., Gasbaoui, B., & Mebarki, B. (2009). Setting up PID DC motor speed control alteration Parameter using PSO. Leonardo Electronic Journal of Practices and Tech

xviii. Yu, K.W., & Hu, S. C. (2006). An Application of AC servo motor by using PSO based sliding mode controller (SMC). IEE conference on Systems, Man, and Cybernetics

xix. Jalilvand, A., Kimiyaghalam A., Ashouri A., & Mahdavi M. (2008), Advance Particle Swarm Optimization (APSO) Based PID Controller Parameters Tuning.12th IEE International Multitopic Conference

xx. Samanta, B. (2008). Design of Intelligent Ship Autopilots using Particle Swarm Optimization. IEE Swarm Intelligence Symposium