Proceedings of the 2016 IEEE/SICE International Symposium on
System Integration, Sapporo Convention Center, Sapporo, Japan,
December 13-15, 2016

Speed Control Technique for Conveyor Using PSO based PID with Programmable Logic Controller

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Abstract— **This work focuses on use of particle swarm optimization (PSO) to identify the optimal PID controller gains in speed control of a conveyor system. The proposed method is implemented on Mitsubishi Q series-UDV PLC with a number of encoder sensors and a built-in Ethernet module to monitor the feedback. To verify the performance of the proposed technique, we apply the optimal gains, which are determined offline by PSO, to the simulator and actual model. The experimental results show that the proposed PSO based PID controller provides lower transient fluctuation and smaller steady-state error compared to other previous approaches.**

I. INTRODUCTION

Due to the simplicity and robustness of PID control systems, PID controllers have been used widely in most industrial plants. Control engineers have been looking for some efficient algorithms used to determine the optimal gains of the PID system. In recent years, many intelligence algorithms have been proposed to optimally tune the PID parameters. Among those algorithms, particle swam optimization (PSO) outperforms in terms of its simple definition, easy implementation, strong convergence, and high robustness, and hence, it is well applicable for solving nonlinear problems. PSO was firstly introduced by Kennedy and Eberhart in [1]. Based on the motion of swarm or flock of animals; e.g. birds, fishes, PSO mimics the behavior of individuals in a swarm to maximize the survival of the species. The PSO algorithm solves the optimization problems by the cooperation and competition among the individuals or particles. Similar to genetic algorithms, PSO depends on iteration, yet the algorithm avoids complex operation by its global search strategy for the entire swarm. However, the PSO algorithm still has some disadvantages in inferior local searching abilities and searching accuracy. Various research studies have modified the original PSO algorithm to improve its performance as follows. In [2], the PSO updating equations are improved by use of inertial weight. The work in [3] proposed a cooperative PSO which considers multiple swarms and optimizes different components of the solutions cooperatively. Katare [4] mixed Levenberg-Marquardt with PSO to improve the searching capability. Examples of applications of PSO in control systems are as follows. The study in [5] applied PSO on PenduBot control. The work in [6] proposed modifier PSO for a double inverted pendulum system. In [7], PSO was employed to tune a PID controller for communication systems.

Programmable logic controllers (PLC) have recently been used in most parts of industry automation. Basically, PLC employs a sequence of digital and analog logic functions designed to manipulate appropriate outputs; e.g., the speed of motors. In conveyor systems which are mostly driven by squirrel-cage induction motors [8], speed control tasks are quite challenging [9-12] because they exhibit high nonlinearity and large numbers of parameters, due to the fact that the rotor resistance varies with the operating conditions. Generally, the typical speed control for conveyers requires closed-loop PID implemented on PLC. However, one of the most difficulties in recent PID controllers is the determination of the proper PID gains. Improper use of optimization algorithm may lead to non-optimal solutions.

This paper introduces a novel tuning technique for PID using PSO in typical PLC based industrial conveyer systems. PSO is applied to PID to determine the gains K_p, K_i, and K_d of the controller. These optimal gains can be assigned directly to the instructions which are then internally processed within the PLC module. The proposed PSO based PID for conveyor systems can provides near optimality with few modifications through PLC functions. From experimental results in both simulation and real system testing, our method provides satisfactory responses for transient and steady-state regions compared to other traditional approaches.

The rest of this paper is organized as follows. Section II gives a model for conveyer systems. Sections III and IV discuss the design of the proposed PSO based PID controller and experimental results, respectively. Finally, we conclude our work in section V.

II. MODEL OF MOTOR CONVEYOR SYSTEM

Dynamics model of the induction motor conveyor system is required in controller design. In this section, we explain an induction motor model in a relatively simple expression by using concepts of space vectors and d-q variables. The d and q equivalent circuits of the induction motor conveyor system are shown in Figure 1 and Figure 2, respectively.

Manuscript received August 12, 2016. This work was supported in part supported by the Department of Teacher Training in Mechanical Engineering, King Mongkut's University of Technology North Bangkok.

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978-1-5090-3329-4/16/$31.00

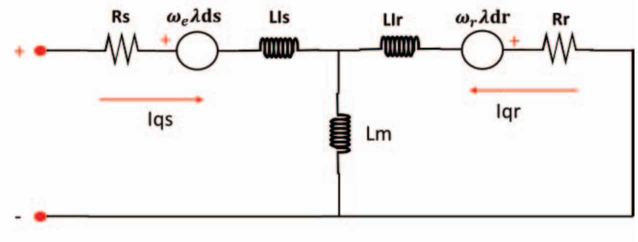

Figure 1. Q-axis equivalent circuit

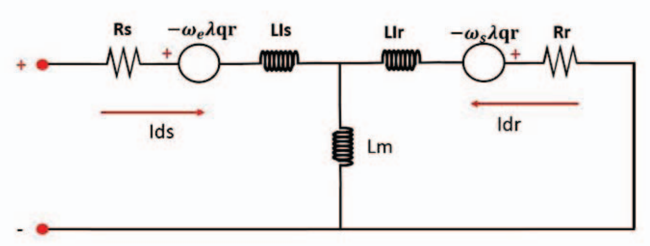

Figure 2. D-axis equivalent circuit

From the above figures, the state-space representation of the motor can be stated as

$$px = Ax + Bu \tag{1}$$

$$x = \begin{bmatrix} I_{qs} & I_{ds} & I_{qr} & I_{dr} \end{bmatrix}^T \tag{2}$$

$$u = \begin{bmatrix} V_{qs} & V_{ds} & 0 & 0 \end{bmatrix}^T \tag{3}$$

where the coefficient matrices A and B can be determined from motor's parameters as expressed in (4) and (5), respectively.

$$A = \frac{1}{\Delta}\begin{bmatrix} R_sL_r & -\omega_eL_sL_r - \omega_rL_m{}^2 & R_rL_m & -\omega_oL_mL_r \\ \omega_rL_m{}^2 - \omega_eL_sL_r & R_sL_r & -\omega_oL_rL_m & -R_rL_m \\ -R_sL_m & -\omega_oL_sL_m & R_rL_s & \omega_rL_sL_r - \omega_eL_m{}^2 \\ \omega_oL_sL_m & -R_sL_m & \omega_eL_m{}^2 - \omega_rL_sL_r & R_rL_s \end{bmatrix} \tag{4}$$

$$B = \frac{1}{\Delta}\begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & Lr & 0 & -L_m \\ -L_m & 0 & L_s & 0 \\ 0 & -L_m & 0 & L_s \end{bmatrix} \tag{5}$$

where $\Delta = L_sL_r - L_m{}^2$ and values of related parameters for this model are given in Table I.

TABLE I. PARAMETER OF THE MOTOR CONVEYER

	Parameters of the Motor Conveyer	
	Parameter	***Value***
1	Rated power P_{rated} [W]	424.7
2	Rated voltage U_{rated} [V]	380
3	Rated frequency f_{rated} [Hz]	50
4	Pole-pairs	3
5	Inductor resistance R_s [Ω]	11
6	Inductor inductance L_s [mH]	527.4
7	Induced part resistance R_r [Ω]	40
8	Induced part inductance L_r [mH]	735.2
9	3-phase magnetizing inductance L_m [mH]	517.5
10	Rated speed [cm/s]	10
11	Mass [kg]	3

A. Speed Control

Synchronous speed of an induction motor is the speed of magnetic field rotation which is dependent on frequency of the power supply and the number of magnetic poles as expressed in (6).

$$N_s = \frac{120f}{p} \tag{6}$$

where N_s = synchronous speed, f = frequency, and p = number of poles

However, the speed of motor's rotor is different from the speed of rotating magnetic field. The percent difference between synchronous speed and real speed is called "slip"; i.e.,

$$s = \frac{N_s - N_r}{N_s} \tag{7}$$

where s = slip, N_s= synchronous speed, and N_r = rotor speed

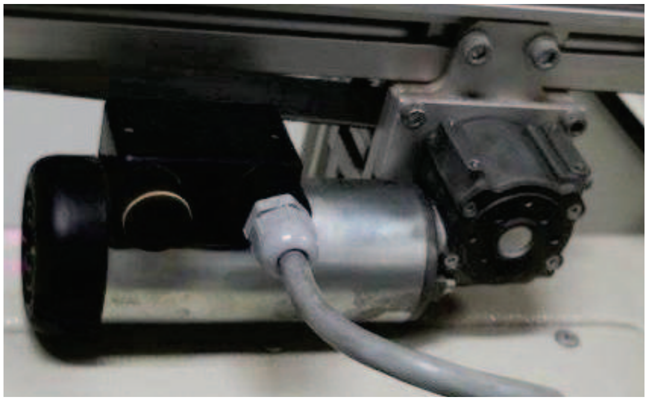

Figure 3. Induction motor for conveyor system

B. Conveyor System

An induction motor used in our conveyor system is shown in Figure 3. As the speed of motor relies on the input voltage, we can control the motion of conveyor belt by adjusting this voltage which is varied from 0 - 10 V in this study.

The photo of the entire conveyor system is shown in Figure 4. An induction motor that rotates the belt in Figure 5 operates with a set of encoder sensors which are installed on the belt to sense the speed and position of the moving container. The structure of our built conveyor system is supported by a platform with six assembly stations. In this system, Mitsubishi Q series-UDV PLC processor is used to control the conveyor system as a main control unit. This PLC supports all of the required control functions; e.g., PWM, PID instructions, and ADC/DAC for feedback information as shown in Figure 6.

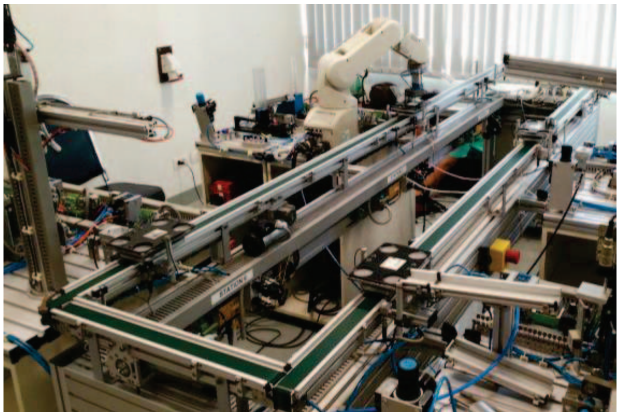

Figure 4. Conveyor system

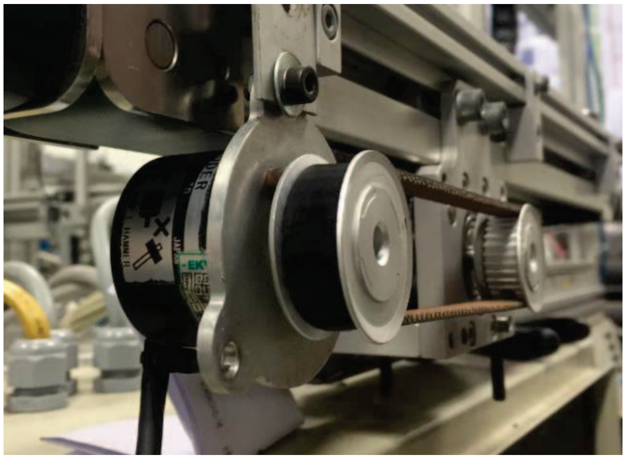

Figure 5. Encoder sensor speed control

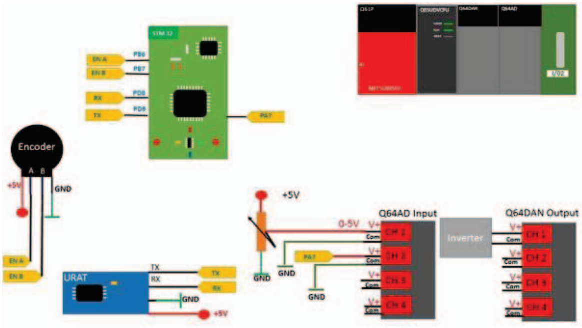

Figure 6. Block diagram of equtivalance circuit

III. CONTROLLER DESIGN

A. PID controller

The objective of this work is to maintain conveyor speed driven by the motor. The speed is sensed by an encoder and sent back through the PLC processor. In this study, we employ the PID control which is a closed-loop system consisting of the summation of proportional, integral, and derivative terms. The term "closed-loop" stands for a continuous status feedback given to the controller. The PID control expression is generally of the form

$$u(t) = K_p.e(t) + K_i \int_0^t e(\tau)d(\tau) + K_d \frac{d}{dt}e(t) \tag{8}$$

where $e(t)$ is the system error between the desired and actual outputs, $u(t)$ is the control force, K_p is the proportional gain, K_i is the integral gain, and K_d is the derivative gain. Diagram of PID controller for conveyor systems is shown Figure 7.

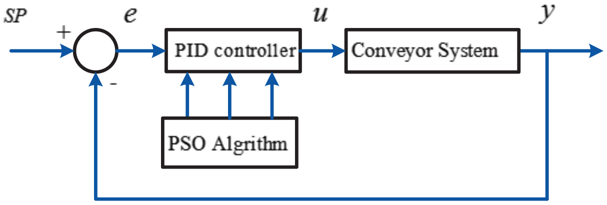

Figure 7. Diagram PID controller for conveyor system

The design procedure consists of determining the PID controller gains in order to construct the desired dynamic transfer function for the speed control equation. Particularly, the proportional gain gives fast response to sudden load changes, whereas the integral gain slowly moves the speed to the set point. The derivative gain can be used to give a very fast response which are highly sensitive to the changes in motor speed. All three PID gains in this study are obtained through PSO algorithm.

B. PSO based PID controller

PSO is a kind of stochastic optimization based on swarm intelligence algorithm. The PSO process starts with initialization of possible solutions to a set of random particles, and then finds the optimal solution through iteration. Particles use the following formula to update their position and velocity for the move.

$$v_{ij}^{k+1} = wv_{ij}^{k} + c_1 r_1 \left(pbest_{ij}^{k} - x_{ij}^{k}\right) + c_2 r_2 \left(gbest_{ij}^{k} - x_{ij}^{k}\right) \tag{9}$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \tag{10}$$

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{11}$$

where v_{ij}^{k+1} is the current speed of particle, v_{ij}^{k} is the speed of particle in the previous generation, r_1 and r_2 are random numbers between [0, 1], c_1 and c_2 are constants, x_{ij}^{k} is the current particle position, x_{ij}^{k-1} is the particle position in the previous generation, $pbest_{ij}^{k}$ is the individual best solution, $gbest_{ij}^{k}$ is the global best solution, and w is the inertia factor. The flowchart of PSO algorithm is given in Figure 8.

PSO is applied to PID system to determine the optimal gain matrix K (which contains K_p, K_i and K_d). Figure 9 shows block diagram of PSO-based PID for the conveyor system. The performance index function or fitness function for the system is represented by

$$J = \frac{1}{2}\int_{0}^{\infty} t.e^{2}(t)dt \tag{12}$$

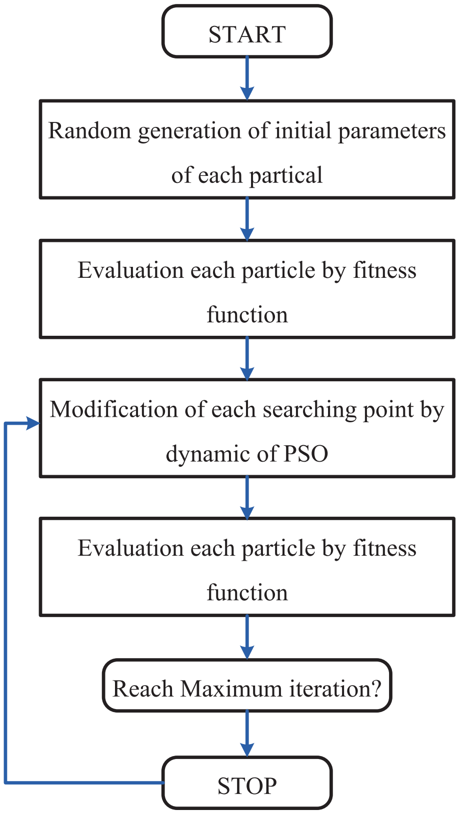

Figure 8. Flowchart of optimization by PSO

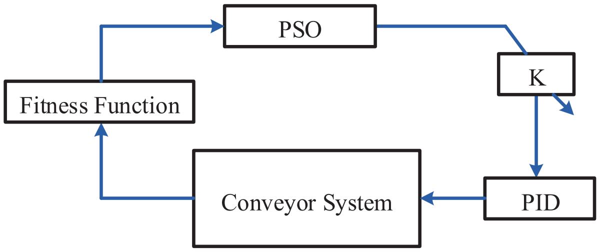

Figure 9. Diagram of PSO based PID controller.

The solution of PSO provides the minimum value of the performance index function in (12). Steps to find the solution by PSO according to Figures 8 and 9 are as follows.

1) Obtain the mathematical model of the conveyor system.

2) Initialize 30 random particles representing the controller gains, and set iteration size to 100.

3) Select the state and control weighting matrices Q and R.

4) Calculate the value of the performance index using Simulink

5) Set the local best, pbest, of each particle and determine the global best, gbest, of the population.

6) Update the global best by comparing the fitness function, and checking the iteration number for the termination criterion. If the termination criterion is met, go to step 8, otherwise continue to step 7.

7) Update particle's velocity (v) and position (x). Loop to step 4).

8) Obtain the optimal gain matrix K which is the last updated gbest.

IV. RESULT AND DISCUSSION

In this section, we firstly apply the PSO algorithm to obtain the optimal gain matrix, K of PID. In PSO problem, thirty PID gain matrices are randomly generated as the initial particles. The solution of optimal gain matrix is iteratively searched using (9)-(11) until the best particle for any iteration becomes steady or the maximum iteration is reached. Next, the solution of the optimal gain from the PSO based method is assigned to the real conveyor system through the instructions of the PLC processor. Further, we compared the outcome from our method with those from other previously proposed methods.

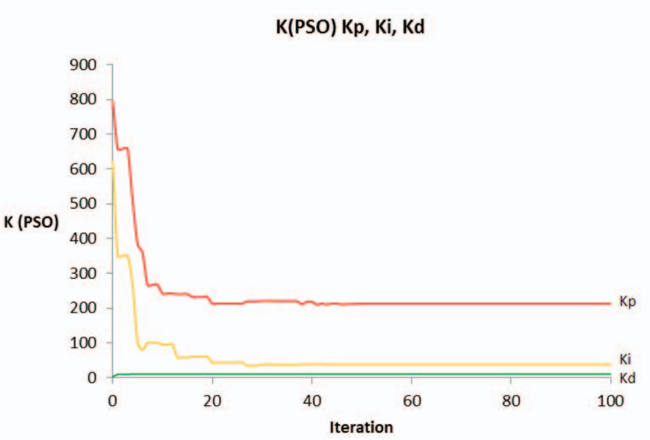

Figure 10. PID gains obtained from PSO

Figure 10 shows the best solution of the PID gains for each iteration. It can be seen in this figure that as a result of the first random generation, the best solution at the beginning of the search is far from the final value. However, with the increasing iteration number, the deviation sharply becomes smaller. For the iteration size of 100 and population size of 30, the components of the global best that represents the optimal PID gains for our experimental conveyor system are given in Table II.

TABLE II. PSO OPTIMAL RESULTS OF PID GAINS

PSO output Result		
K_p	K_i	K_d
224.25	21.52	1.00

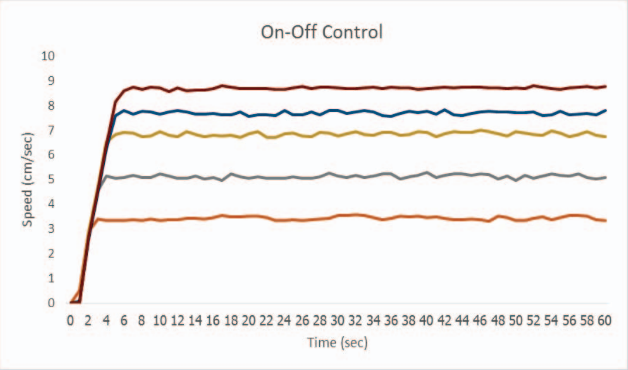

Figure 11. Speed of conveyor system obtained from on-off control method

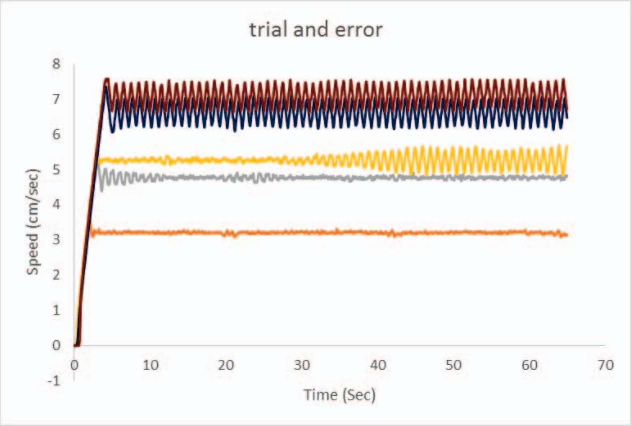

Figure 12. Speed of conveyor system obtained from trial and error based PID control

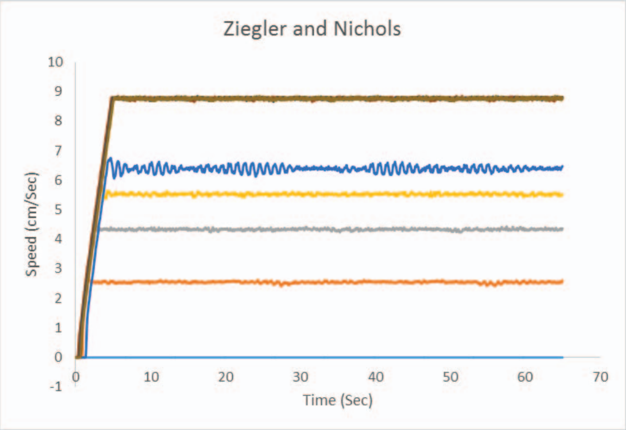

Figure 13. Speed of conveyor system obtained from Ziegler and Nichols control

Figure 11 – Figure 14 show the result of conveyor speed from four different approaches: on-off control, trial-and-error based PID control, Ziegler and Nichols control, and our proposed PSO based PID control, respectively. The target speed levels of the motor are set to be 30% (3.25 cm/s), 60% (5.5 cm/s), 75% (7.0 cm/s), 85% (8.0 cm/s), and 100% (8.75 cm/s) of the rated speed throughout the experiment. To be easily comparable, we also select the initial gains for some methods such that their transient response is similarly bounded.

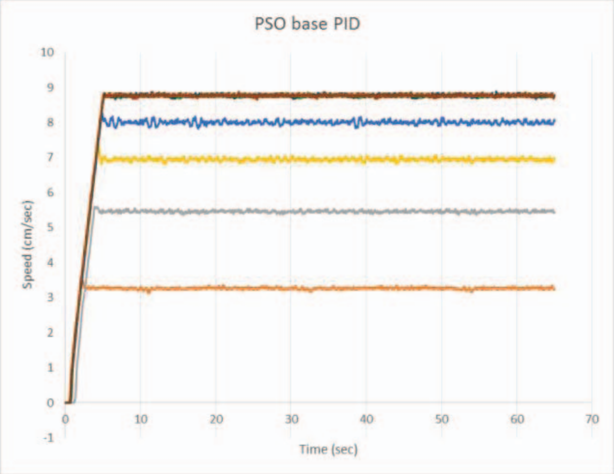

Figure 14. Speed of conveyor system obtained with PSO based PID control

Figure 11 plots the speed of the motor as a result of the on-off approach. The largest gap between the maximum and minimum points for this approach is 0.35 cm/s and the largest steady-state error is 15.38%. Although, a small size motor used in this investigation causes the whole response to be smooth and fast, large systems provides slow response and as a result, on-off control may not be an efficient choice. The speed result from trial-and-error based PID in Figure 12 provides extremely large oscillation compared to the previous method. The largest different between the highest and lowest swing from this method is as large as 0.8 cm/s and its maximum steady-state error is 11.43%. For the Ziegler and Nichols method as shown in Figure 13, the swing and steady-state error are lower than the previous two approaches with the maximum peak-to-peak oscillation of 0.3 cm/s and steady-state error of 6.67%. It can be noticed in Figure 14 that the result from our proposed PSO based PID method outperforms others with relatively low oscillation at around 0.2 cm/s maximum peak-to-peak difference and the worst-case steady-state error is only 5.25%.

V. CONCLUSION

This paper proposed a new method to control the speed of induction motor used in conveyor systems. We employ PSO algorithm to determine the PID gain matrix. The optimal solution obtained from our proposed technique is then evaluated and compared with several approaches through the PLC processor. The experimental results reveal that the PSO based PID technique provides better response compared to others with only 0.2 cm/s maximum peak-to-peak difference which is 4 times lower than trial-and-error based PID method and around 1.5 times lower than on-off and Ziegler&Nichols methods.

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