American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-03, pp-179-186
www.ajer.org
Research Paper Open Access

An application of Ion Motion Optimization algorithm to the problem of finding DC motor controller parameters

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ABSTRACT *In practice, the PI controller is often used to stabilize the DC motor speed due to its low cost and ease of installation. Therefore, various methods of PI controller parameter determination have been proposed. In particular, the method of adjusting the parameters of the PI controller based on the optimal search algorithm gives the best results. In this paper, the authors present how to apply the Ions Motion Optimization (IMO) algorithm to find the parameters of the PI controller in stabilizing the speed of a DC motor. The results achieved through simulation and experimentation show that the IOM algorithm converges quickly and the controller has very good performance.*
KEYWORDS *DC motor, PI Controller, IMO Algorithm, Tuning PID controller*

Date of Submission: 14-03-2021 Date of acceptance: 28-03-2021

I. INTRODUCTION

DC motors are widely used in industrial applications such as rolling mills, steel mills, electric trains and cranes. The advantages of DC electric motors are wide control range of speed, high starting torque, fast and compact response. [1].

In industry, for controlling DC motors, with low control quality requirement, PI controller is often used due to its low cost. The essence of this approach is to minimize the error between the actual motor speed and the desired set speed. When using a PI, within certain time limits the motor reaches the desired speed smoothly and operates stably at that speed throughout the entire running time. [2].

The problem here is that it is necessary to define the Kp and Ki parameters of the controller so that the best control quality is achieved. There are many methods to calibrate PI controller parameters, the most common is the Ziegler-Nichols method. However, for some systems, calibrating the PI controller by this method requires a rather time-consuming experimental process due to the effects of interference and device error on the test signal. This makes it difficult to correct the parameters of the PI controller to achieve a good value. In this case, it is necessary to use additional optimization algorithms to search around the operating point of the Ziegler-Nichols algorithm. In this case, it is necessary to use additional optimization algorithms to search around the operating point of the Ziegler-Nichols algorithm. Therefore, recently, a lot of published works have proposed applying optimal algorithms to adjust the parameters of the PI controller such as genetic algorithm (GA), Particle Swarm Optimization (PSO) [5].

The IMO is an optimization algorithm published by Javidy in 2015 [6]. This is an algorithm that is inspired by the movement of ions in nature. The performance results of the algorithm evaluated by the author on 10 benchmark functions are very convincing [6]. This has attracted a series of studies to apply IMO to some specific problems such as the load economic dispatch. [8], cancer diagnosis [7].

From the above results, the authors found that it is completely possible to apply the IMO algorithm to search the coefficients of the dc motor speed controller (Kp, Kd) to improve the quality of control.

The next part of this paper will present in more detail the steps of applying the IMO algorithm to the problem of determining the parameters of the PI controller to stabilize the DC motor speed, including:

- Determine the transfer function of the object using MATLAB Identification Toolbox
- Construction of PI controller according to Ziegler - Nichols's method
- Adjust parameters of the PI controller using IMO algorithm
- Evaluate the results through simulation and experimentation.

II. DETERMINE THE TRANSFER FUNCTION OF THE OBJECT

2.1. System description

Fig.1. The experimental model of DC motor control

To verify the applicability of the IMO algorithm in determining the parameters of a PI controller, the authors derived from the experimental model of a DC motor speed control system described in Fig.1. The system consists of 3 parts:

- DC motor: We use YASKAWA B1T20E engine with parameters described in [9].
- Motor driver circuit: The authors use the H-bridge circuit L298 to control the speed of the DC motor by controlling the motor's input voltage according to the PWM [10].
- Microcontroller: Arduino UNO is used to install the motor control program. This microcontroller is often used in experimental models due to its low cost and ease of installation.

2.2. System model identification

In the next step, the authors use experimental methods to identify the system model in order to build a suitable controller. This process includes:

- Step 1: Collecting experimental input/output data of the system.
- Step 2: Preprocessing the data to remove unreliable measurement values.
- Step 3: Selecting identification method (identifying model with parameter or without parameters, analysis of transient response, least squares method ...)
- Step 4: Selecting model structure
- Step 5: Determine the model parameters according to the selected method / algorithm.

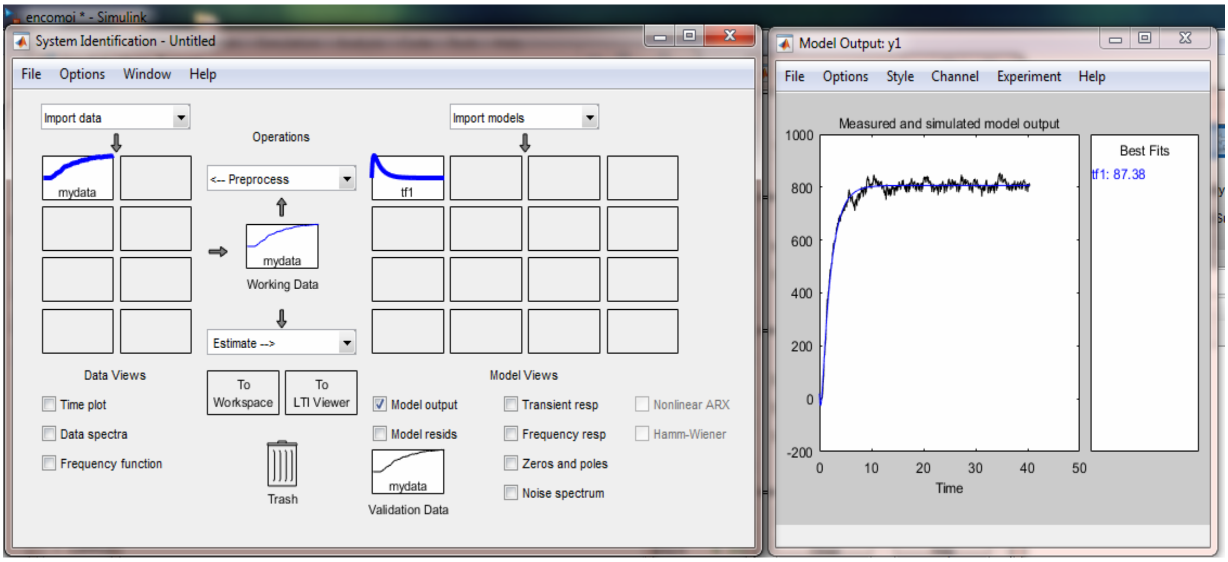

Fig.2. Identify the system model using the MATLAB Identification Toolbox

Fig.2 illustrates the results of using the MATLAB Identification Toolbox to identify the system according to the 5 steps mentioned above [11]. We choose the model “tf1” with a fit of 87.38% and this is a simple model that is easy to perform later calculations. From there, we determine the transfer function of the system according to (1).

$$G(s) = \frac{333.4}{s^2 + 4.276s + 2.067} \quad (1)$$

III. CONSTRUCTION OF PI CONTROLLER ACCORDING TO ZIEGLER-NICHOLS METHOD

The classic PI controller for DC motors is described by Equation (2). Where, u(t) is the controller output signal, e(t) is the deviation between the real motor speed and desired speed. The problem is that it is necessary to find the coefficients Kp, Ki such that the speed of the engine quickly reaches the set amount and is stable over time.

$$u(t) = K_P e(t) + \frac{K_P}{T_I}\int_0^t e(t)dt \quad (2)$$

Experimental method Ziegler - Nichols [13] is used to determine the parameters of the PI controller based on the transient response of the control object. When we act on an object (DC motor) with Step function as input, we get an S-shaped output (Fig.3). From this output, we define three parameters including L (time delay constant), k (amplification factor) and T is the time constant inertia). Finally, we compute the coefficients like (3).

$$Kp = 0{,}9T/(k*L),\ T_I = L/0{,}3. \quad (3)$$

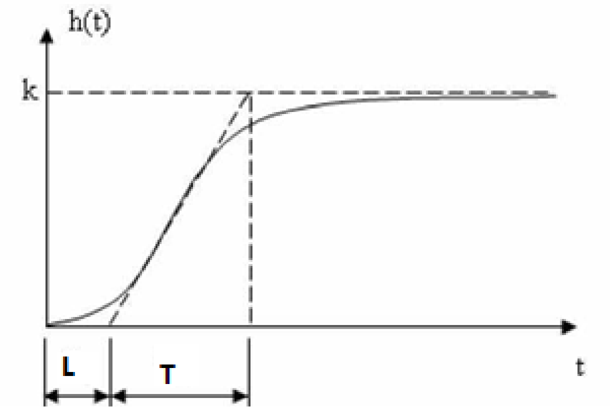

Fig.3. Illustration of the Ziegler-Nichols method

When the system delay time is significant, i.e., a large L value, not to mention the effect of the noise and the error of the measuring equipment, *{Kp_Z-N, Ki_Z-N}* obtained from Equation (3) will do not satisfy the quality of the controller. These values need to be adjusted experimentally, which takes quite a while before applying. Therefore, it is necessary to support the above refinement process with an intelligent algorithm on the computer such as the IMO algorithm.

IV. ADJUST THE PI CONTROLLER PARAMETERS USING THE IMO ALGORITHM

4.1. IMO algorithm

The IMO is an optimization algorithm published by Javidy in 2015 [6] inspired by the behavior of charged particles (anions and cations) in practice. Ions with charges of the same sign repel each other, while opposite charges attract each other (Fig.4).

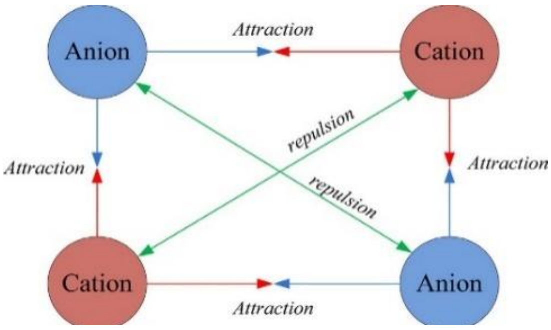

Fig.4. Conceptual models of anions, cations, attraction and repulsion [6]

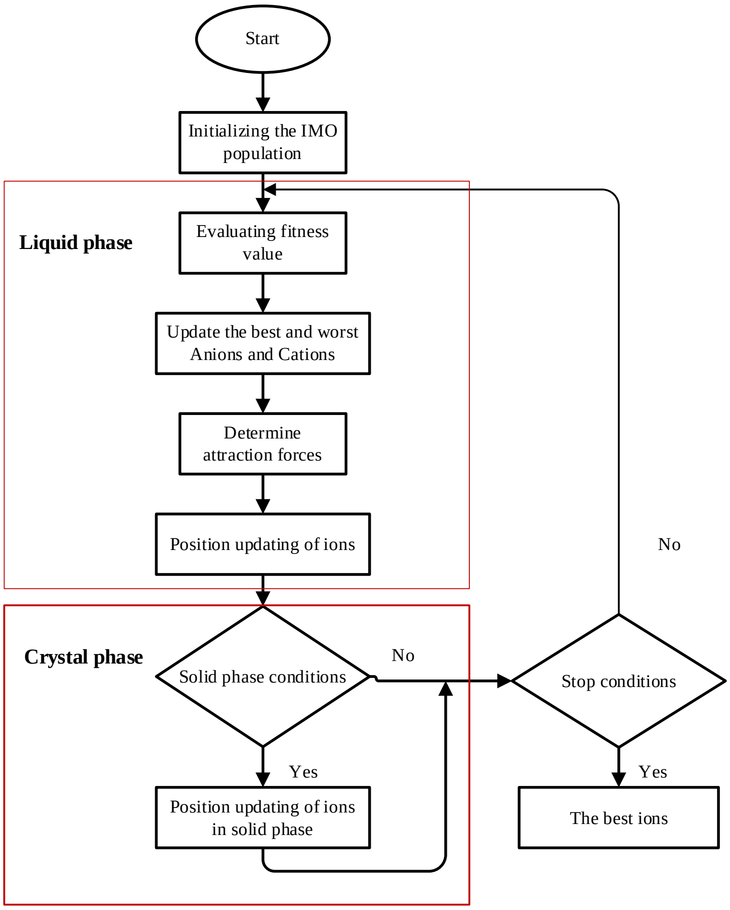

Fig.5. Basic steps of IMO algorithm

In the IMO algorithm, each ion represents a solution of the optimization problem. The ions are again divided into two groups of anions (negative ions) and cations (positive ions). Based on the distribution of these ions, attraction and repulsion force move the ions around the search space. The IMO algorithm will move ions to the best ions with opposite charges. anions move towards the best cation, while cations move towards the best anion. Thus, after a while, the solution will converge on the best anion and cation.

In the IMO algorithm, to ensure the mechanism of diversification and enhancement, ions are transformed through two completely different phases: liquid phase versus crystal phase.

In the liquid phase, ions in a liquid are easier to move freely. In addition, attraction forces between ions with opposite charges is more than repulsion forces between ions with the same charge. In this phase IMO ignores repulsion forces to explore the search space.

In the crystalline phase, the ions were converged at an optimal point and convergence took place. However, due to the undefined shape of the search space, convergence can take place for the local optimization. This phase therefore provides a mechanism for the locally optimal escape of ions. Fig.5 describes the four steps of the IMO algorithm in detail, including:

Step 1. Initialize IMO population

- Generate parameters of IMO algorithm such as number of iterations M, random value

- Generate randomly initial populations of N/2 Anions and N/2 Cations. Each individual in the population is a solution to the search problem

Step 2. Update the ion position according to the liquid phase

- Calculate fitness values of each ions. The fitness value is the object function to be achieved
- Identify the best anion ($Abest$) and the best cation ($Cbest$).
- Calculate the distance of other anions to the best cation, the distance of other cations to the best anion according to (4).

$$AD_{i,j} = d(A_{i,j}, Cbest_j)\ CD_{i,j} = d(C_{i,j}, Abest_j) \tag{4}$$

- Determine the attraction force between the j component of the i anion in the population to the best cation, between the j component of the i cation in the population to the best anion.

$$AF_{i,j} = \frac{1}{1 + e^{-0.1/AD_{i,j}}},\ CF_{i,j} = \frac{1}{1 + e^{-0.1/CD_{i,j}}} \tag{5}$$

- After the force calculation process, the new anion and cation positions are updated as follows:

$$A_{i,j} = A_{i,j} + AF_{i,j} x (Cbest_j - A_{i,j}) \tag{6}$$

$$C_{i,j} = C_{i,j} + CF_{i,j} x (Abest_j - C_{i,j}) \tag{7}$$

Step 3. Update the ion position according to the crystal phase

$$
\begin{array}{l}
if\ (CbestFit) >= CworstFit/2\ and\ AbestFit >= AworstFit/2 \\
\quad if\ rand() > 0.5 \\
\quad\quad A_i = A_i + \phi_1 \times (Cbest - 1) \\
\quad else \\
\quad\quad A_i = A_i + \phi_1 \times Cbest \\
\quad endif \\
\quad if\ rand() > 0.5 \\
\quad\quad C_i = C_i + \phi_2 \times (Abest - 1) \\
\quad else \\
\quad\quad C_i = C_i + \phi_2 \times Abest \\
\quad endif \\
\quad if\ rand() < 0.05 \\
\quad\quad Re-initialized\ A_i\ and\ C_i \\
\quad endif \\
endif
\end{array} \tag{8}
$$

Step 4. Check the iteration and stop conditions of the algorithm

- If the end condition is met (e.g., maximum number of iterations) then terminate the process and give the result which is the best ion among the Anions and Cations.
- If the stop condition is not reached, repeat from step 2.

4.2. Application of IMO algorithm to the problem of finding optimal parameters of PI controller

Fig.6 depicts the use of the IMO algorithm to find out optimal controller parameters. Each ion will represent the parameters of a controller (*CSi*). The adaptability of each ion is evaluated by a fitness function that gives us the fit_i. values. The ion {CSi} is considered to be the most suitable if it has the smallest fit_i value. When the convergence condition is guaranteed, we will find the ion that contains the controller's most suitable parameters. Here, the fitness function is the Integral absolute error (IAE) calculated using Equation (9).

$$fit_i(k) = \sum_{j=1}^{M} \left| e_j(k) \right| \tag{9}$$

Where: $e(k)$ is the difference between the theoretical output and the actual output;

M is the number of samples to be examined.

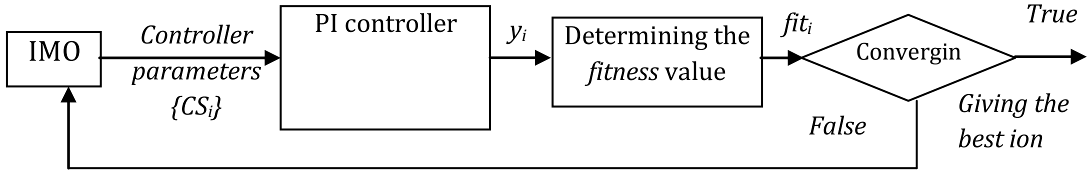

Fig.6. **PI controller parameter optimization using IMO algorithm**

The task of the IMO algorithm applied here is to find the optimal values *{Kp_opt, Ki_ opt}* of the PID controller, where the fitness function reaches the minimum value. In order to limit the search space of IMO algorithm, we assume that optimal values *{Kp_opt, Ki_ opt}* are distributed around the value *{Kp_Z-N, Ki_Z-N}* obtained from Ziegler-Nichols. The corresponding search limits for the two parameters of the PID controller are as follows:

$$\begin{aligned} \alpha K_{p\_Z\_N} &\le K_{p\_opt} \le \beta K_{p\_Z\_N} \\ \alpha K_{I\_Z\_N} &\le K_{p\_opt} \le \beta K_{I\_Z\_N} \end{aligned} \quad (10)$$

In which, the coefficients α and β are chosen such that the search space is large enough to contain the desired optimal value. Simulation results on the DC motor speed control system model show that α = 0.01 and β = 100 are satisfied.

V. EVALUATION OF RESULTS THROUGH SIMULATION AND EXPERIMENTATION

To verify the results of the proposed method, we use MATLAB Simulink tool according to the diagram as in Fig.7 to simulate and evaluate the aforementioned DC motor stability at 700 rpm for some PI controller. The controllers under investigation are Ziegler-Nichols Controller (PI_ZN), PI controller with parameters regulated by GA algorithm (PI_GA), PSO algorithm (PI_PSO) and IMO algorithm (PI_IMO). Operation of the controllers is investigated for 20 seconds.

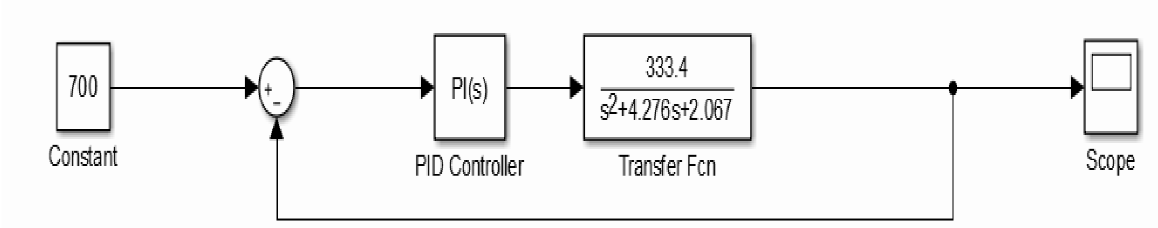

Fig.7. PI controller operation simulation diagram

With the PI_ZN controller, by experiment we have calculated k = 1.9352, L = 1.2 and T = 2.8, from which we can determine the values Kp = 1.5627 and Ki = 0.3907.

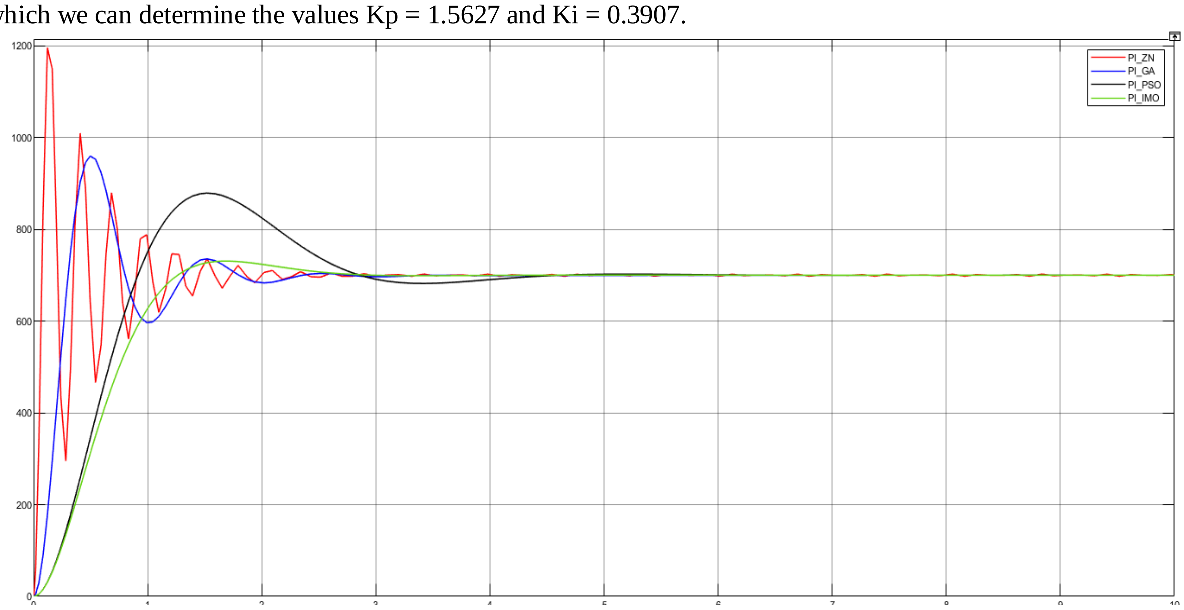

Fig. 8. Control characteristics of PI controllers

For the PI_GA and PI_PSO controllers we use MATLAB's built-in tool with default parameters. To implement PI_IMO controller, we build our own program to find coefficients Kp, Ki. The search time of the optimal controllers was set at 5 minutes to match the quality of the controllers. The characteristics of the controllers are shown in Fig. ***8***. Specific parameters of the performance quality of the controllers after 5 minutes of calibration are described in Table 1. These parameters include the rise time, the setting time, overshoot, IAE, Integrated Squared Error (ISE). Thereby, it can be seen that the PI_ZN controller has poor quality due to the error of the experimental measurements. The additional use of the optimal search algorithm makes the controller PI_GA, PI_PSO, PI_IMO have significantly improved quality. PI_IMO gives the best control quality. We also extended the search time to 15 minutes and found that the controllers are all converging to Kp = 0.0208, Ki = 0.5555. This suggests that IMO gives faster convergence times compared to the rest of the algorithms.

Table 1. Some parameters of the control quality after simulation

	PI_ZN	PI_GA	PI_PSO	PI_IMO
Kp	1.5627	0.1260	0.0209	0.0208
Ki	0.3907	0.4589	0.3213	0.5565
The rise time	0.0480145	0.203787	0.815262	0.818658
The settling time	1.95741	2.11898	2.26358	2.27272
Overshoot	76.291	36.9244	4.39627	4.36391
IAE	28113.3	15042	12018.3	11993.8
ISE	1.14519e+07	8.04932e+06	7.2214e+06	7.2017e+06
MSE	29900.5	63380.4	85969	85734.5

From the results obtained by the simulation, we conduct experiments according to the connection diagram described in Figure 9 to verify the operation of the PI_IMO controller on the real device. The actual results of the PI_IMO controller with the set speed of 700 rpm are shown in Figure 10. From this result, the real controller works quite effectively, the measured speed is always in line with the reference speed, response time speed within the allowable limit. The characteristic curve fluctuates very slightly around the speed setting.

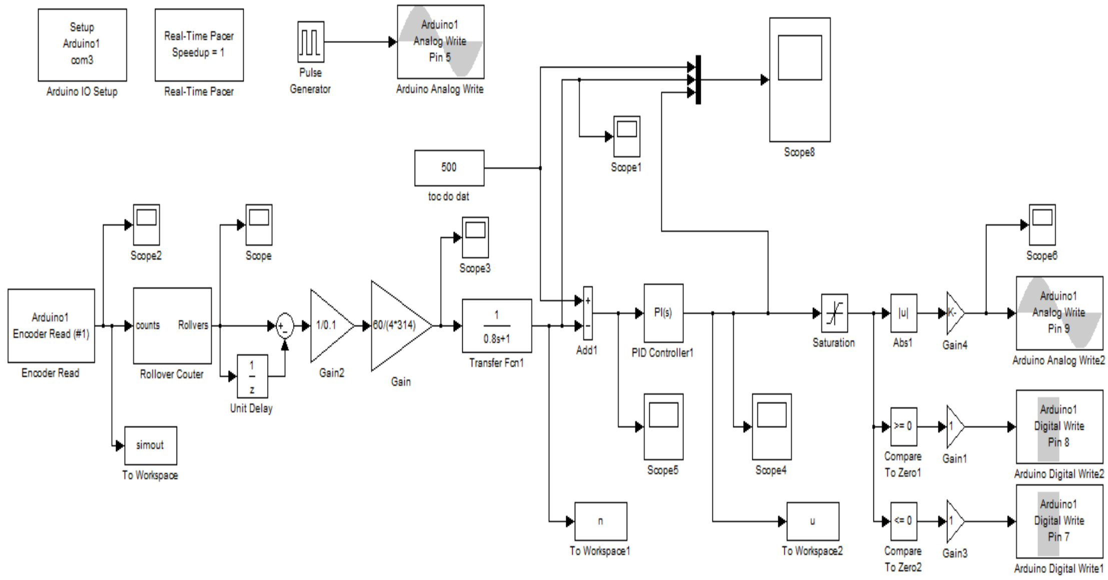

Fig.9. Realistic PI controller installation block diagram

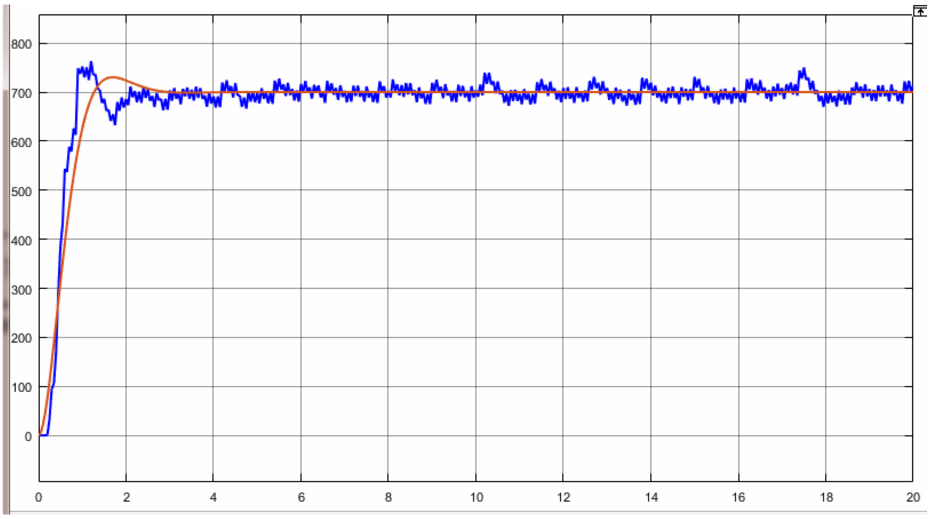

Fig.10. Operational results of ideal and actual PI_IMO controller with set speed 700 rpm

VI. CONCLUSION

In this paper, the author presents detailed steps for using IMO algorithm to search the parameters of a PI controller to stabilize the DC motor speed. From a hardware model illustrating the problem of stabilizing one-dimensional motor speed, the author proceeds to identify the real object model by MATLAB Identification Toolbox. Next, based on the transfer function obtained from the real model, the author calculates the parameters of the classical PI controller according to the Ziegler-Nichols method. Finally, the IMO algorithm was used to find optimal parameters for this PI controller around the Ziegler-Nichols operating point. The test results in simulation and practice show that the controller using IMO algorithm has good control quality. In particular, the simulation results also show that, compared to other optimal search algorithms such as GA, PSO, the IMO algorithm converges faster. This proves that it is completely possible to apply the IMO algorithm for finding the controller parameters in practice.

ACKNOWLEDGMENT

This research was supported by the ICTU research grant (under project # T2020-07-15). We thank our colleagues from the ICTU and TNUT who provided insight and expertise that greatly assisted the research.

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