Optimal Comparison Using MOWOA and MOGWO for PID Tuning of DC Servo Motor

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***Abstract*— The purpose of the study is to investigate the tuning of parameter gain PID controller for a DC servo motor. In this research, comparison between the meta-heuristic algorithm of Multi-objective Whale Optimization Algorithm (MOWOA) and Multi-objective Grey Wolf Optimizer (MOGWO) for PID tuning are made. Three objective functions are employed i.e. minimal settling time (t_s), minimal overshoot (MP), and minimal steady state error (e_{ss}). The MOWOA gives a better result based on the hypervolume indicator.**

***Index Terms*—PID controller, MOWOA, MOGWO, hypervolume, optimization algorithm, feedback control**

I. Introduction

A DC servo motor has been widely used in many industrial applications. These applications focus mainly on control of speed and position. Various control techniques such as PID, LQR, Fuzzy Logic are employed. However, the most popular technique is the PID method because of its simplicity and robustness [1]. The PID controller is first proposed in 1922 by Minomorsky[2]. It consists of three-term controllers, K_P proportional gain, K_I integral gain, K_D derivative gain.

In order to tune the PID, various techniques such as a trial-and-error, Ziegler-Nichols and state feedback technique are utilized. The trial-and-error depends on the operator experiences. This can take a long period of time to get a satisfied values. For the Ziegler-Nichols tuning [3], it usually leaves some overshoot of the output. The state feedback often requires complex mathematical model.[3]

The meta-heuristic algorithm is also a popular tuning technique because of its simplicity. The algorithm is developed to many others algorithm such as the Genetic Algorithm (GA), the Ant Colony Optimization (ACO), the Particle Swarm Optimization (PSO) [4], the Cuckoo Search (CS) [2].

This paper proposes a tuning algorithm for PID controllers of the a DC servo motor systems. Three characteristics of the response are considered that are a settling time (t_s), an overshoot (MP), a steady-state error (e_{ss}). Minimization of these values are set as three objective functions.

The work compare between two optimization techniques which are the Multi-objective Whale Optimization Algorithm (MOWOA)[5] and the Multi-objective Grey Wolf Optimizer (MOGWO)[6]. Both techniques are new meta-heuristic optimization algorithm and their solutions are unlikely to give premature convergence. They also utilize non-dominated solution [5][6] for Pareto front. Their performance are indicated by hypervolume (HV) for optimum point.

This paper is arranged as follows: starting with introduction, Section 2 presents the system model for feedback control. Section 3 demonstrates how to tune the PID with MOWOA and MOGWO while its results and discussion is shown in Section 4. The work ends with conclusion in Section 5.

II. System Model

A conventional feedback control loop with parallel PID controllers is presented by the block diagram in Fig. 1. The $G_P(s)$ is the plant of a DC servo motor (GMST2012) of Googol Technology (see Fig. 2). The $G_C(s)$ is the PID controller. The PID controller receives an error signal $E(s)$, and generates control signal $U(s)$ to the plant. In this case the disturbance $D(s)$ is set to 0, referent input $R(s)$ is velocity setting 2,000 (rpm) and the output of system is $C(s)$

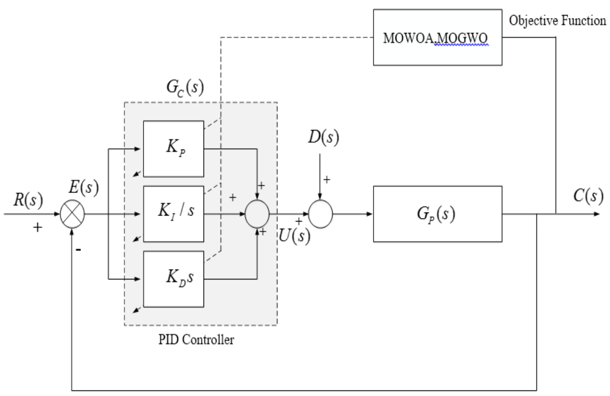

Figure 1. The block diagram of PID controller system.

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Figure 2. DC servo motor (GMST2012).

Transfer function of the system is presented in (1). The relation of three control elements of the PID; K_P proportional gain, K_I integral gain, K_D derivative gain, are shown in (2).

$$G_P(s) = \frac{1}{0.052s+1} \times \frac{1}{0.12s+1} \quad (1)$$

$$u(s)|_{PID} = K_P + \frac{K_I}{s} + K_D S \quad (2)$$

III. PID Tuning with MOWOA and MOGWO

The multi-objective optimization is a design assigned to determine optimal point. For the problem that has more than one objective functions, it also has more than one optimum solution. The traditional combination of these results is called a set of Pareto optimal solutions or a Pareto front which is viewed in the objective function domain.

A typical mathematical formulation of multi-objective optimization can be expressed as:

$$Mimimize : F(x) = \{f_1(x), f_2(x), \ldots, f_o(x)\} \quad (3)$$

Constraints

$$g_i(x) \leq 0, i = 1, \ldots, m$$
$$h_i(x) = 0, i = 1, \ldots, l$$
$$L_i \leq x_i \leq U_i i = 1, \ldots, n$$

When x=$[K_P,K_I,K_D]^T$, f_i represents of design variable and objective functions respectively. $g_i(x)$ and $h_i(x)$ are the inequality and equality constraints while L_i, U_i is lower and upper bound constraints. $m, l, n,$ is number of variable and o is number objective function.

A. Objective Function

The design problem in this study has three objective functions which are the minimum settling time (t_s), the minimum overshoot (MP), and the minimum steady-state error (e_{ss}). Detailed can be descripted as follows.

1) Settling time minimization

The settling time is defined as the time for response to reach, and stay within 2% of its final value. A desired value of the control system is the minimum settling time.

$$\text{FOBJ1} = \min(t_s) \quad (4)$$

2) Overshoot minimization

The system should have a minimum percent overshoot.

$$\text{FOBJ2} = \min(\text{MP}) \quad (5)$$

3) Steady state error minimization

The final value of the system should approach its reference input, thus, a minimum steady-state error is needed.

$$\text{FOBJ3} = \min|e_{ss}| \quad (6)$$

Inequality constraints

$$t_s \leq 1.5 (\text{sec})$$

$$\text{MP} \leq 4.3\%$$

$$e_{ss} \leq 10\%$$

These values are from the GMST2012 guide.

B. Multi-objective

An external Pareto archives a non-dominated solution. The step by step procedure of implementation of the proposed multi-objective algorithm is outlined below :

Step 1: Initialize population of design variable vector is parameters K_P,K_I,K_D

$$K = \begin{bmatrix} k_1 \\ k_2 \\ \vdots \\ k_n \end{bmatrix} = \begin{bmatrix} k_{1,1} & \cdots & k_{1,d} \\ k_{2,1} & \cdots & k_{2,d} \\ \vdots & \cdots & \vdots \\ k_{n,1} & \cdots & k_{n,d} \end{bmatrix}_{0 \leq k \leq 10}$$

When k is the parameters K_P,K_I,K_D of PID controller, d is the dimensionality.

Step 2: Evaluate the fitness evaluation of a design variable vector. For the third objectives f_1,f_2,f_3, and the vector solution F is feasible solutions in inequality constraints.

$$F(K) = \begin{bmatrix} f_1(k_1) & f_2(k_1) & f_3(k_1) \\ f_1(k_2) & f_2(k_2) & f_3(k_2) \\ \vdots & \cdots & \vdots \\ f_1(k_n) & f_2(k_n) & f_3(k_n) \end{bmatrix}$$

Step 3: Determine the non-dominated solution (NS) solution is shown in Fig. 3. They store and update a set of non-dominate in Pareto archive (P) (P=P+NS).

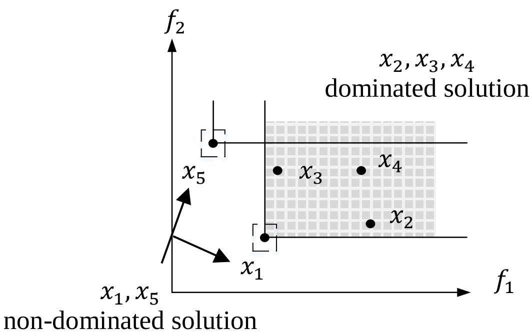

Figure 3. Non-dominated solutions.

Step 4: Select the best solution from Pareto archive using the roulette wheel in Fig. 4 and grid mechanism [6] in Fig. 5.

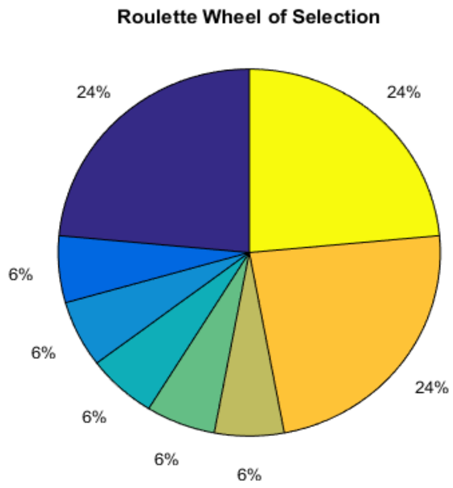

Figure 4. The roulette wheel.

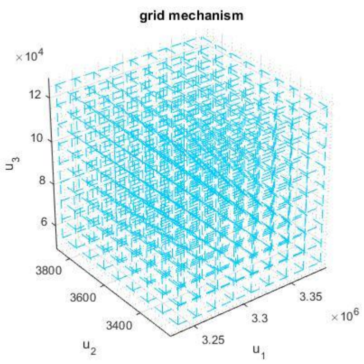

Figure 5. The grid mechanism of Three objective functions.

Step 5: Update the best solution if there are better solutions and the next generation is generated.

Step 6: Run the algorithm is repeated until a termination criterion is met.

C. Numerical Experiments

The calculation is conducted by using an Intel(R) Core(TM) i7-5500u CPU @ 2.4GHz RAM 8 GB notebook to run a MATLAB software. The general parameters of all algorithms such as the population size or number of search agents (n_a) = 30, number of population = 3, mumber of iteration (n_{iter}) = 500, size of Pareto archive ($n_{archive}$) = 300, number of grid per each dimension(nGrid) = 10, grid inflation parameter(alpha) = 0.1, vector $\vec{\alpha}$ from 2 to 0, lower bound constraints(L_i)= 0, upper bound constraints (U_i) = 10, The MOGWO setting, leader selection pressure parameter beta (β) = 4, alpha (α) = 0.1

1) Multi-objective Whale optimization algorithm (MOWOA) (Algorithm 1)

The WOA algorithm mimicking the hunting behavior of humpback whales, mathematical model of encircling prey, spiral bubble-net feeding maneuver, and search for prey [7] . Pseudo code is shown in Fig. 6.

Pseudo code : WOA (Algorithm1)

Initialize the whales population X_i (i=1,2,…n)
Calculate the fitness of each search agent
$X^*$the best search agent
while (t<maximum number of iterations)
    for each search agent
        Update a,A,C,l,and P
        if1(P<0.5)
         if2(|A|<1)
            Update the position of the current search agent
         else if2(|A|≥1)
            Select a random search agent (X_{rand})
            Update the position of the current search agent
         end if2
        else if1(P≥0.5)
            Update the position of the current search agent
        end if1
    end for
    Check if any search agent goes beyond the search space and amend it
    Calculate the fitness of each search agent
    Update X^* if there is a better solution
    t=t+1
end while
return X^*

Figure 6. Pseudo code of the WOA algorithm[7]

2) Multi-objective Grey Wolf Optimizer (MOGWO) (Algorithm 2)

The GWO is social hierarchy and hunting behavior of grey wolf packs, mathematical models of the social hierarchy, tracking, encircling, and attacking prey are provided[8]. Pseudo code is shown in Fig. 7.

Pesudo code : GWO (Algorithm2)

Initialize the grey wolf population X_i (i=1,2,…n)
Initialize a,A, and C
Calculate the fitness of each search agent
X_α= the best search agent
X_β= the second best search agent
X_δ= the third best search agent
while (t<maximum number of iterations)
    for each search agent
        Update the position of the current search agent
    end for
    Update a,A, and C
    Calculate the fitness of each search agent
    Update X_α, X_β, and X_δ
    t=t+1
end while
return X_α

Figure 7. Pseudo code of the GWO algorithm[8]

IV. RESULT AND DISCUSSION

The multi-objectives tested function optimized by using proposed MOWOA and MOGWO comparative algorithms are shown in Fig. 7 – Fig. 11. These figures reflect the convergence quality of Pareto archive of optimization. The performance compared based on the hypervolume (HV) indicator and reference point 1.5 is increasing. The reference point for calculating the hypervolume, Results that obtained using algorithms MOWOA,MOGWO are reported in the Table 1. The hypervolume of the MOWOA(2.4576) which is more than the MOGWO (2.4573). Therefore, the MOWOA outperform the MOGWO, which parameters K_P=1.4948, K_I=9.4872, K_D=0. These tuning give characteristics of a transient response; settling time (t_s) =0.2261 sec, overshoot(MP)=0%, steady state error (e_{ss}) = 3.4476e-5. Fig. 12 shows a transient response of tuning PID controller from the MOWOA, the MOGWO and the suggested values from the GMST2012's manual guide.

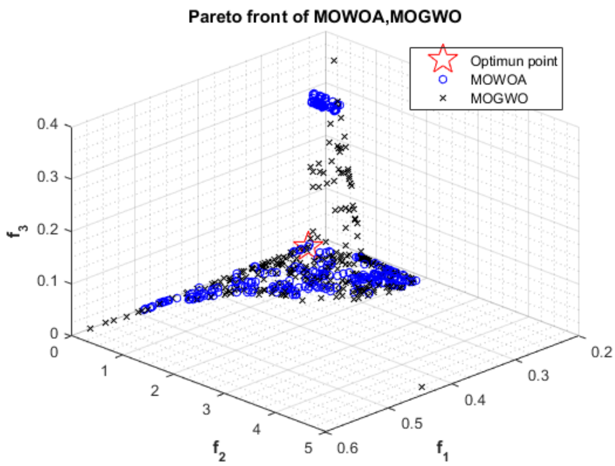

Figure 8. Pareto front 3 objective functions (f_1,f_2,f_3)

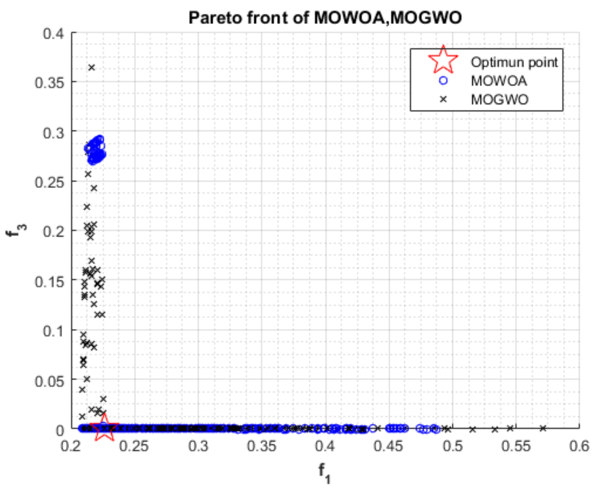

Figure 9. Pareto front 3 objective functions (f_1,f_3)

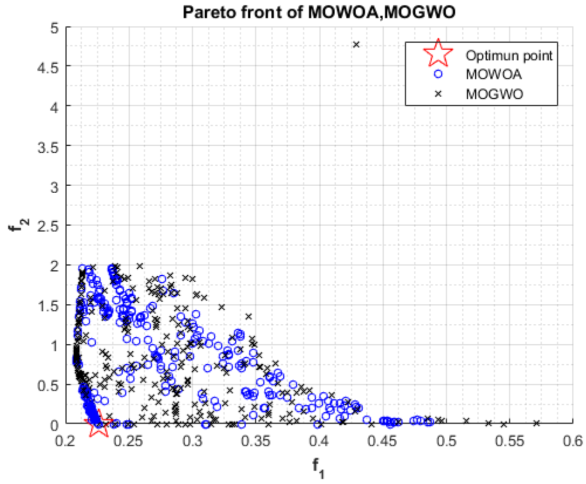

Figure 10. Pareto front 3 objective functions (f_1,f_2)

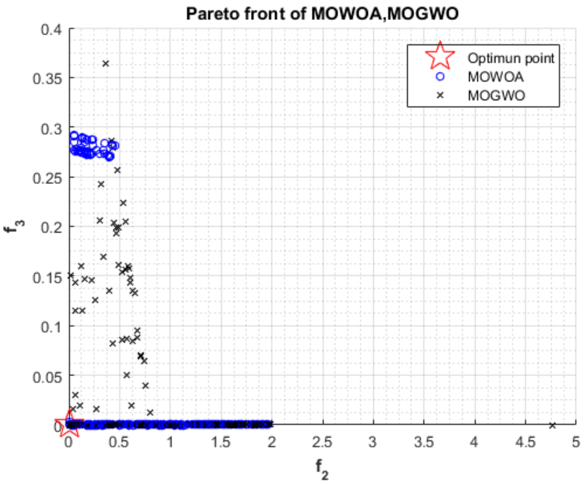

Figure 11. Pareto front 3 objective functions (f_3,f_2)

TABLE I. COMPARISONS RESULTS FROM THE MOWOA, MOGWO, AND THE SUGGESTED MANUAL GUIDE.

Algorithm	Parameter			Objective			HV
	K_P	K_I	K_D	t_s(sec)	MP	E_{ss}	
MOWOA	1.4948	9.4872	0	0.2261	0	3.4476e-5	2.4576
MOGWO	1.4938	9.4854	0	0.2262	0	3.4127e-5	2.4573
Manual	0.4	4.5	0	0.5482	1.2653	25.3	-

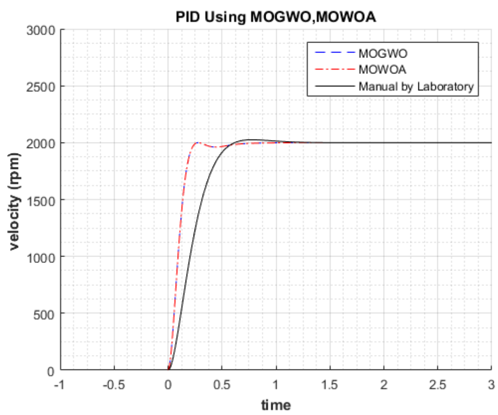

Figure 12. transient response system

V. Conclusion

The study shows a PID controller tuning results from new meta-heuristic optimization algorithm MOWOA and MOGWO with the suggested manual guide. The tested system is a speed control of the a DC motor (GMST2012).

The optimum results show that the MOWOA gives a better optimization algorithm on the hypervolume indicator. Transient response characteristics of the system performs a satisfied that are settling time (t_s) = 0.2261sec, overshoot(MP) = 0%, steady-state error (e_{ss}) = 3.4476e-5.

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