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# Performance enhancement of large-scale linear dynamic MIMO systems using GWO-PID controller

**Mohammed Qasim Sulttan[1], Salam Waley Shneen[2], Jafaar Mohammed Daif Alkhasraji[1]**
[1]Department of Electromechanical Engineering, University of Technology, Baghdad, Iraq
[2]Nanotechnology and Advanced Material Research Center, University of Technology, Baghdad, Iraq

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**ABSTRACT**

The multi-input multi-output (MIMO) technique is becoming grown and integrated into wireless wideband communication. MIMO techniques suffer from a large-scale linear dynamic problem, it will be easy to adjust the proportional integral derivative (PID) of a continuous system, unlike the nonlinear model. This work displays the tuning of the PID controller for MIMO systems utilizing a statistical grey wolf optimization (GWO) and evaluated by objective function as integral time absolute error (ITAE). The instantaneous adjusting characteristic GWO approach is the criterion that distinguishes such a combination-proposed strategy from that existing in the traditional PID approach. The GWO algorithm searching-based methodology is used to determine the adequate gain factors of the PID controller. The suggested approach guarantees stability as the initial scheme for a steady state condition. A combination of ITAE combined with the GWO reduction method is adopted to reduce the steady-state transient time responses between the higher-order initial scheme and the unit amplitude response. Simulation outcomes are illustrated using MATLAB software to show the capability of adopting the GWO scheme for PID controlling.



***Corresponding Author:***

Mohammed Qasim Sulttan
Department of Electromechanical Engineering, University of Technology
Baghdad, Iraq
Email: mohammed.q.mohammed@uotechnology.edu.iq

## 1. INTRODUCTION

Large-scale systems with multi-input multi-output (LS-MIMO) became encouraging for research the field of multi-antenna technology since its capability of continuously enhancing spectral efficiency [1]-[3]. Such a technique employs a large-scale antenna formed as an array at a base station (BS) to secure the data for multiple users concurrently. Besides the increase the spectral efficiency, high-order MIMO can significantly enhance the reliability and security of transmission systems, consequently, performing outstanding spatial multiplexing gains, that is to say, massive MIMO particularly enhance such transceivers' approaches contrary to the limited scale networks [1], [4]. It is worth mentioning that for point-to-point channels, the complexity concerning the receiver side has more significant than that of the transmitter side, For instance, the complexity grows exponentially as the number of antenna increases on the transmitter side. While for the MIMO scenario, besides the receiver side, a great concern is paid to the transmitter aspect since the propagating signal needs to deliver to more than one user simultaneously [5]-[8].

In this context, in terms of analysis or controller structure, the mathematical definition of most physical techniques results in higher-order differential formulas which are difficult to deal with. It is hence beneficial and occasionally essential to discover the potential of determining some formula of the identical style with as low order as possible. Such a mathematical model could be deemed to sufficiently mirror the required performance of the system under investigation. As a consequence, a comprehensive understanding, decreasing computational complexness, and easy system design [9]-[11]. The complexity of the dynamic scenarios is one of the significant tasks especially in wireless communication, more specifically, LS-MIMO technology. In real-time, it is hard to use a complicated mathematical model since it contents of several mathematical formulas notably many variables.

This is attributed to the need to perform the simulations within an adequate amount of time as well as save in memory capacity, such the requirements should come with highly reliable results [12]-[14]. The principles model order reduction (MOR) algorithm differs by relying on the preferred basis characteristic. In other words, designing all the fundamental vectors as simply as possible and/or reducing the basis condition number. Without a doubt, the saving procedure in the reduction model pursues to obtain the required characteristics [9]. Thus, MOR has been intensively investigated seeking to employ progressively in complex dynamic networks such as optimization and control. A large and growing body of literature has investigated the MOR techniques for better understanding large-scale linear dynamical (LSLD) scenarios. For instance, using familiar examples, Sastry *et al.* [15] proposed a novel simple method to combat the computational complexity for higher-order MIMO systems by applying with modified Routh approximation technique integrated with the initial time moments and Markov factors matching approach. The outcomes showed the responses to the suggested method matched the response of the already methods that existed in the literature.

Research by Bhatnagar and Gupta [16] introduced a new algorithm based upon gray wolf optimization (GWO) for both single-input single-output (SISO) and MIMO systems. Integral square error (ISE) has been considered as a measuring objective function to signify the reduction percentage. The results proved the superiority of the suggested algorithm. Recently, Suman and Kumar [17] proposed a simplified approach based on balanced singular perturbation approximation (BSPA) to preserve complete factors with appropriate precision by utilising MOR. The outcomes achieved showed the effectiveness of the suggested approach by comparing the response acquired by other strategies in the literature. Several approaches have been introduced to obtain the required performance.

In this context, employing nature besides the social behaviour of birds, bees, and animals is considered an intelligent evolutionary technique aiming at the goals achieved represented by improving the velocity, accuracy and stability of the solution approach [18]-[21]. One approach like the Taylor series expansion demands a pre-conjecture location for recursive steps. Such an algorithm provides poor results if the pre-conjecture location is inaccurate [22]. Concerning Y.T. Chan's method, the maximum likelihood computational is applied with least-squares estimation employed. Both of these algorithms obtained significant results in a low Gaussian noise condition. More recently, heuristic strategies occupied an interest in such a field aiming to achieve the optimum solutions. For example, the particle swarm optimization (PSO) approach was introduced [23], [24]. Throughout this method, the stability and precision of the position have been considerably enhanced [25]-[27].

The research [28] introduced a new intelligent optimization strategy in 2014. The possibility and validation of the method were checked through criterion measurement and based on various field science implementations during the subsequent years. The motivation of this algorithm was inspired by the imitation of biome behaviour such as the community system of the grey wolf of prey hunting strategy. GWO method gained much attention in the research community and has become a dependable alternative strategy in comparison to conventional optimization owing to its mechanism characterized by simplicity, flexibility, high robustness and rapid convergence. Additionally, demands fewer factors for setting and a small operator in comparison to other evolutionary methods, and a fast computing process [29]-[32]. Although several reduction techniques were studied for LS-MIMOL to improve its response in terms of stability and reliability, high robustness is still required for such complex systems. The remaining parts of the paper proceed as follows. Section 2 presents a brief description of each part used in this work. Section 3 describes simulation results and discussion. Finally, section 4 presents concluding remarks.

## 2. SYSTEM MODEL AND PROBLEM STATEMENT

Performance indication techniques are commonly employed to describe the outcomes of a proportional integral derivative (PID) controller. The aim here is to design a model efficiently with the expected stipulations.

Thus, in this section, a brief description presents the main techniques which were adopted.

### 2.1. Fitness functions or implementation indices

The performance indication techniques are commonly employed to describe the outcomes of a PID controller aiming to design a model efficiently with the expected stipulations [33]. Several approaches of fitness functions or implementation indices, for instance, integral absolute error (IAE), ISE, integral square time absolute error (ISTAE), and integral time absolute error (ITAE) were implemented to investigate their performance. In this work, the method called ITAE is adopted as an indication approach to the system's performance as well as its robustness. The features of such an approach are that it has acceptable damped oscillation with a fairly low overshoot value. In (1) defined such an approach while Figure 1 exhibits the block diagram.

$$\text{ITAE} = \int_0^\infty t\,|e(t)|\,dt \tag{1}$$

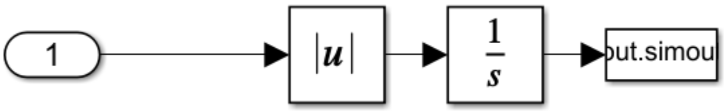


Figure 1. ITAE block diagram

### 2.2. Proportional integral derivative controllers

The use of a PID controller in the current work to improve the system stability besides decreasing the steady-state error and reducing the time constant to make the system response as faster as possible. Accordingly, the PID controller is a practical technique and easy to implement in control systems. In this vein, expression (2) with the aid of Figure 2(a) defined the SISO-PID controller.

$$u(t) = k_p\,e(t) + k_i \int_0^t (t)dt + k_d \frac{d}{dt} e(t) \tag{2}$$

where $k_p,\ k_i,$ and $k_d$ represent proportion gain factor, integral gain factor, and derivative gain, respectively, while $e$ stands for error and $t$ denotes simultaneous time.

For simplicity, it was reported that dealing with MIMO as two SISO loops separately is more applicable. Thus, in the current work, a heuristic approach combined with PID controller design and ant colony optimization (ACO) algorithm is considered for evaluating MIMO systems. Accordingly, for the MIMO scheme, the configuration comprises two controllers $\text{PID}_1$ and $\text{PID}_2$ as shown in Figure 2(b). Mathematically, the system can be expressed as [34]:

$$\text{PID}_1 = k_{p_1} + \frac{k_{i_1}}{s} + k_{d_1} s$$

$$\text{PID}_2 = k_{p_2} + \frac{k_{i_2}}{s} + k_{d_2} s \tag{3}$$

### 2.3. Gray wolf optimization

The GWO is an important optimization technique for meta-heuristic. Its precept is to simulate the behaviour of grey wolves in nature to chase the victim in a cooperative way. It is characterised as different from other techniques in terms of model structure and it has a better performance in finding the optimal design of nonlinear double-layer grids. The mathematical expression of the model of the GWO algorithm is [35].

Consider the original high-order system as a transfer function with "$4r^{th}$" order shown in the expression (4):

$$G_r(s) = \frac{N(s)}{D(s)} = \frac{a_0 + a_1 s + a_2 s^2 + ... + a_{r-1} s^{r-1}}{b_0 + b_1 s + b_2 s^2 + ... + b_{r-1} s^{r-1}} \tag{4}$$

where $a$ and $b$ stand for pre-defined scalar constant values. Now the system after reducing the order with "$n^{th}$" order is written in the expression (5) as:

$$G_n(s) = \frac{N(s)}{D(s)} = \frac{c_0 + c_1 s + c_2 s^2 + ...c_{n-1} s^{n-1}}{d_0 + d_1 s + d_2 s^2 + ...d_n s^n} \tag{5}$$

The reduced order response can be derived from the original high-order system response using the fitness function (ITAE) according to expression (1) and the PID controller. Figure 3 show the block diagram of the reduced order model of the system. At this point in time, the GWO algorithm role starts to choose the best solution (system model with less order, expression (5) of the system which appears in Figure 4. The role of the GWO algorithm is manifested in the flowchart of the GWO algorithm in Figure 3.

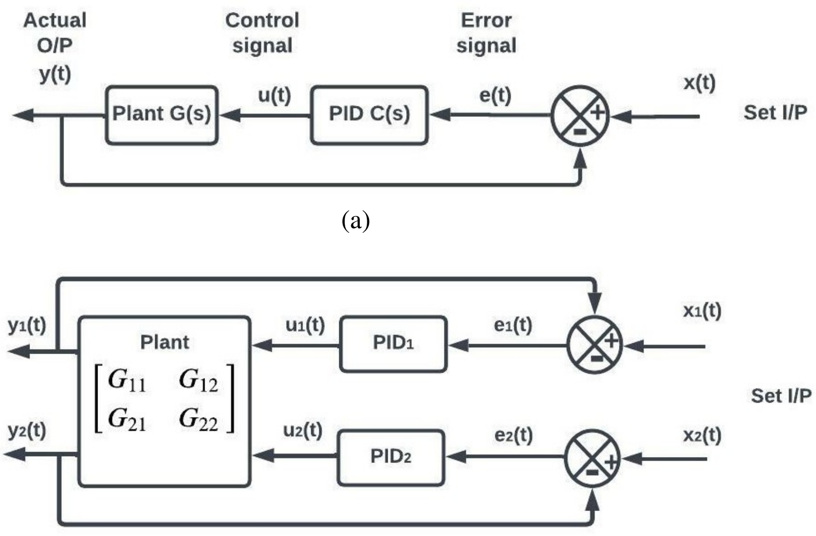


Figure 2. Block diagram of closed loop structure of SISO and MIMO system, (a) SISO system (b) MIMO system [34]

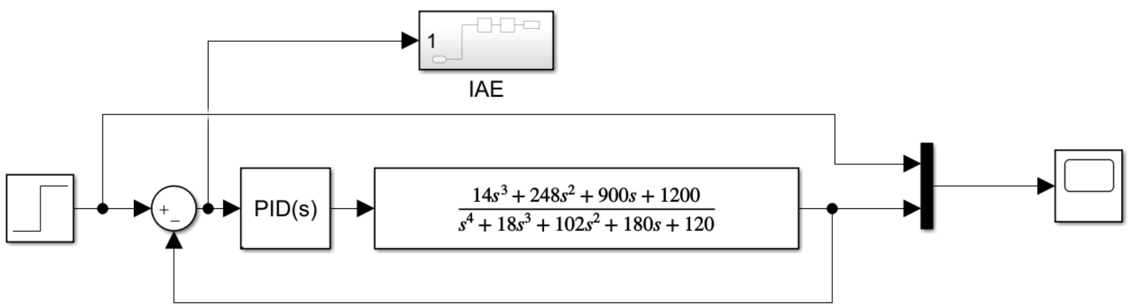


Figure 3. Block diagram of the reduced order model of the system

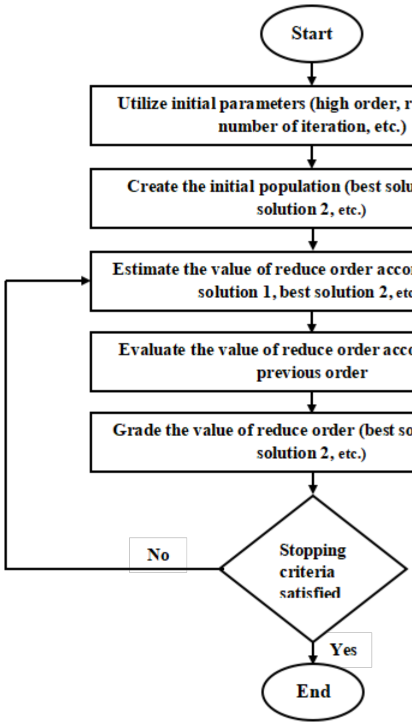


Figure 4. Flowchart of the GWO algorithm for reduced the order of the system

## 3. SIMULATION RESULTS AND DISCUSSION

The objective of this research is to design of ITAE-PID controller and tuned it by GWO with the system's T.F. In this method, the denominator and numerator factors of the reduced model are selected by minimizing the ITAE between the transient reactions of the actual and reduced prototype by a differential equation of the unit step input. The T.F of the system is in an open loop as shown in expression (6):

$$\text{T.F} = G = \frac{14s^3 + 248s^2 + 900s + 1200}{s^4 + 18s^3 + 102s^2 + 180s + 120} \tag{6}$$

The step response of the system is shown in Figure 5. This figure shows three curves, the first one is the response of the system without a controller, the second one is the response of the system acting with a PID controller and the third one is the response of the system acting with a GWO-PID controller. The measured parameters for different $\text{ITAE}_{\text{min}}$ for the ITAE-PID scenario were indicated in Table 1. Additionally, it can be extracted in Figure 5 the essential information and arranged in Table 2.

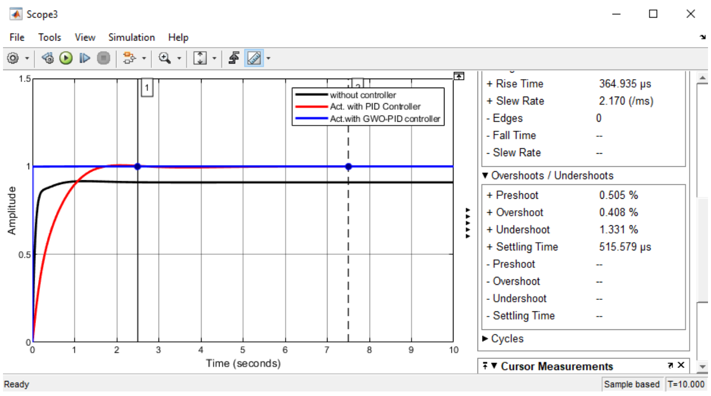


Figure 5. Step responses of GWO/PID method with ITAE as an objective function

Table 1. The tuned parameters for different $ITAE_{min}$ for ITAE-PID scenario

| $ITAE_{min}$ | 1.1170 | 0.6089 | 0.3897 | 0.1669 |
|---|---|---|---|---|
| $k_p$ | 500 | 137.3458 | 66.9656 | 500 |
| $k_i$ | 500 | 133.3991 | 15.4448 | 500 |
| $k_d$ | 34.5397 | 35.3112 | 469.5709 | 123.8387 |

Table 2. The extracted outcome from the system

| | System without controller | System with PID control | System with GWO-PID controller |
|---|---|---|---|
| Rise | 149.474 $ms$ | 973.451 $ms$ | 364.935 $\mu s$ |
| Over | 0.201 % | 0.505 % | 0.408 % |
| Under | 1.908 % | 1.235 % | 1.331 % |

As it is well known that improving the performance of any system requires adopting optimum indications, which are assumed to be indications to enhance the performance of systems. In this context, design-appropriate controllers for any system are examined through one or more performance indexes for a highly effective system and within the required specifications. These indications can be recognised through in (2) to (5). Figure 6 show the relationship between the cost function and iterations. It can clearly observe that the indications that achieved the curve to obtain a minimum cost function-value based on the ITAE=0.6089 method are $K_p = 137.34$, $K_i = 133.39$, and $K_d = 35.31$.

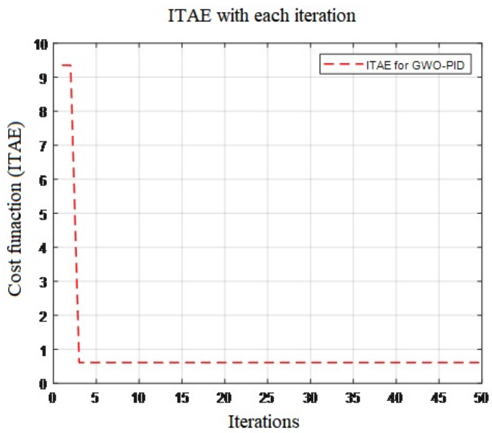


Figure 6. The relationship between the cost function and iterations

According to the outcomes in Table 2, we can conclude that the speed response of the system with the GWO-PID controller is faster than the system with only the PID controller and the system without the controller, which goes back to the value of rising time. The second point that can be concluded is the relative stability that goes back to the value of the present overshoot, the system without the controller has the best stability (overshoot=0.201%) compare to the system with the GWO-PID controller (overshoot=0.408%) and with only the PID controller (overshoot=0.505%). Based on the above, it can be noted that the adoption of the GWO optimization method with the PID controller aims to reduce the order in a way so that the denominator polynomial of a higher-order transfer function is reduced by the ITAE approach.

## 4. CONCLUSION

This paper is illustrated the performance evaluation of the GWO/PID approach combined with ITAE as an objective function in enhancing the system's step response for the MIMO scheme. A MATLAB Simulink and m-file code for the control algorithm were used in the design. The simulation was accomplished for PID via GWO. Although the complexity of the suggested approach was incremented owing to an increase in tuning factors, the results showed an enhancement could be achieved based on the suggested method. Finally, the response result proved that the tuning optimization strategy obtained a powerful index, a fast response, a miniature overshoot, a steady error reduction, and a stable response.

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## BIOGRAPHIES OF AUTHORS

**Mohammed Qasim Sulttan** Asst. Prof. Dr. Mohammed Qasim Mohammed Sulttan received his B.Sc. (Electrical Engineering and Education) and M.Sc. (Engineering Educational Technology/Electrical Engineering) from the University of Technology Iraq in 1996, 20005 respectively and Ph.D. from Huazhong University of Science and Technology China (Information and Communication Engineering) During 2016. Work at the Department of Electromechanical Engineering from 1998 to 2005 as an engineer and from 2005 until now as a lecturer. His research areas are electrical-electronics engineering, communication and information engineering, and MIMO techniques. He can be contacted at email: mohammed.q.mohammed@uotechnoloy.edu.iq.

**Assist. Prof. Dr. Salam Waley Shneen** Assist. Prof. Dr. Salam Waley Shneen, educational background: July 2016 Ph.D., degree in Electrical Engineering-Power Electronic, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology (HUST). Nov 2005 M.Sc., degree in Engineering Educational Technology-Electrical Engineering, Technical Education Department, University of Technology, Iraq-Baghdad. July 1998 B.Sc., degree in Electrical Engineering and Education, Technical Education Department, University of Technology, Iraq-Baghdad. Oct 1994 Diploma in Electrical Technology, Technical Instructors Training Institute, Iraq Baghdad. 1992 High School Bakaloria degree Preparatory Technical School (Electrical Section), Almashtal Technical Secondary School Iraq-Baghdad. Work Experience 1998-2005 Engineer in: Electronic Lab., Digital Electronic Lab., Communication Lap., Fundamental of Electric Engineering Lab. Cad Lab. In Technical Education Department, University of Technology, Iraq-Baghdad. 2005-2016 Assistant Lecturer in: Electronic Lab., Lecturer Advanced Electronic, Lecturer Fundamental of Electric Engineering, Technical Education Department, Electromechanical Department University of Technology, Iraq-Baghdad. 2016-2017 Lecturer in: Electronic Lab. Fundamental of Electric Engineering Lab., Lecturer Electronic Circuits, Lecturer Fundamental of Electric Engineering with Electrical and Electronic Circuits Electromechanical Department University of Technology, Iraq-Baghdad. 2017-10 Apr.2022 Lecturer in: Energy and Renewable Energies Technology Center, University of Technology, Iraq-Baghdad. 10 April 2022 today Lecturer in: Nanotechnology and advanced material research Center, University of Technology, Iraq-Baghdad. He can be contacted at email: salam.w.shneen@uotechnology.edu.iq.

**Jafaar Mohammed Daif Alkhasraji** received his B.Sc. and M.Sc. degrees from Electromechanical Engineering and Laser and Optoelectronics Engineering Departments, University of Technology, Baghdad, Iraq, in 2001, and 2008, respectively, and Ph.D. degree from Newcastle Newcastle Upon Tyne, United Kingdom, in 2019. Dr. Jafaar has been a member of the syndicate of Iraqi engineers since 2002, and the IEEE community since 2016. His research interests include optical communication, wireless communication, DSP, MIMO, underwater optical wireless communication, coded and precoded OFDM communications systems, and adaptive array signal processing and estimation. He can be contacted at email: jaafar.m.dhaif@uotechnology.edu.iq.