Application of Grey Wolf Optimization in Control of Ball Hoop System with IAE Performance Indice

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Abstract: The present work deals with application of Grey Wolf Optimization (GWO) algorithm in determining the optimal parameters of proportional-integral derivative (PID) controller for control of ball hoop system. The GWO is a bio inspired meta-heuristic algorithm. Here, integral absolute error (IAE) has been taken as an objective function for tuning the parameters of PID controller by GWO. Comparison of proposed GWO/PID scheme with other existing techniques has also been shown. It has been observed that proposed GWO/PID approach with IAE as an objective function gives less overshoot and settling time when compared with existing approaches in the literature.

Keywords: Ball Hoop System, PID Controller, Grey Wolf Optimization, Optimal Control, IAE.

1. INTRODUCTION

Mostly industrial processes are controlled using proportional-integral-derivative (PID) controllers. The popularity of PID controllers is due to their robust performance and their functional simplicity [1-3]. The three important parameters of PID controllers are proportional gain (K_p), integral constant (K_i) and derivative constant (K_d). To achieve the desired response with PID controllers these three constant should vary, it is called tuning of the controller. From many years classical methods like; Ziegler-Nichols (Z-N) and Cohen-Coon (C-C) have been used for optimal tuning of PID controllers [4-5]. Due to nonlinearity in plants, many times the conventional PID controllers tuning methods fail to achieve desired response. Over the past two decades, meta-heuristic algorithms for optimization have become highly popular among researchers, due to simplicity, flexibility, random search and avoidance of local optima [6-7].

Numerous meta-heuristic algorithms are available in literature to tune the parameters of PID controllers, such as; Genetic Algorithm (GA) [8], Particle Swarm Optimization (PSO) [9], Chaotic Particle Swarm Optimization (CPSO) [10], Adaptive Hybrid PSO (AHPSO) [11], Artificial Bee Colony Optimization (ABC) [12], Bacterial Foraging Optimization (BFO) [12-13], Chaos driven Differential Evolution algorithm (DE_{Chaos}) and Self-Organizing Migrating Algorithm ($SOMA_{chaos}$) [14] are already available in the literature to tune the parameters of PID controller for ball hoop system.
The present work deals with application of GWO algorithm in tuning the parameters of PID controller for control of ball hoop system with IAE as an objective function. GWO is a bio inspired heuristic algorithm inspired by both the social hierarchy of wolves as well as their hunting behavior. The search starts with population of randomly generated wolves (solutions) in GWO. During hunting (optimization) process, these wolves estimate the prey's (optimum) location through an iterative procedure [8-11].

2. BALL HOOP SYSTEM

A BH system is easy to construct and because of its good dynamics, it is preferred by control engineers for investigations. The BH system is analogous to the liquid 'slosh' problem. The ball hoop (BH) system mimics the complex dynamics of the oscillations of a liquid in a container when the container is moving and undergoing changes in velocity and direction. This 'liquid slosh' is significant because the movement of large quantities of liquid can strongly influence the movement of the container itself, which is usually undesirable and often dangerous [10-14, 20].

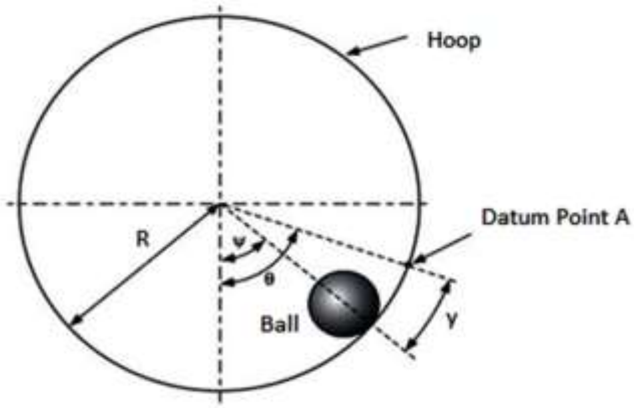

Figure 1: Model of ball hoop system

The basic model of ball hoop system which is 4^{th} order system, is shown in Figure 1 [11, 20]. The key system variables of BH system are: hoop radius: R, ball radius: r, ball mass: m, hoop angle: θ, ball angles with vertical (slosh angle): ψ, ball position on the hoop: y, input torque to the hoop: $T(t)$.

The Ball and Hoop System [11-12, 20] illustrate the dynamics of a steel ball that is free to roll on the inner surface of a rotating circular hoop. The inside edge of the hoop has groove on it, so that a steel ball can roll freely inside the hoop. The motor rotates hoop continuously .When the hoop is rotated, the ball will tend to move in the direction of hoop rotation. At some point, gravity will overcome the frictional forces and the ball will fall back. This process will repeat, due to which the ball to have oscillatory motion.

The transfer function of BH system is given by [11-12]:

$$G_{BH}(s) = \frac{y(s)}{\theta(s)} = \frac{1}{s^4+6s^3+11s^2+6s} \quad (1)$$

3. PROBLEM STATEMENT

In general, the equation of PID controller is given as:

$$G(s) = k_p + \frac{k_i}{s} + k_d \quad (2)$$

In equation (ii), the three important parameters of PID controllers are proportional gain (K_p), integral constant (K_i) and derivative constant (K_d).

The present work involves application of the GWO algorithm in control of the Ball and Hoop system with the help of a PID controller. The three parameters of the PID controller are tuned by GWO algorithm with IAE objective function.

The integral absolute error (IAE) performance index is given by Equation (3):

$$IAE = \int_0^\infty |e(t)|dt \quad (3)$$

The simulink model representation of above IAE in MATLAB is shown in Figure 2.

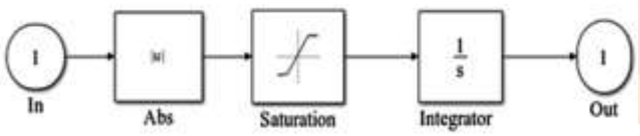

Figure 2: Simulink model representation of IAE

4. GREY WOLF OPTIMIZATION

The grey wolf optimization (GWO) is a bio inspired meta-heuristic algorithm inspired by the social hierarchy of wolves as well as their hunting behavior. In GWO algorithm search starts with population of randomly generated wolves called, solutions. During hunting (optimization) process, these wolves estimate the prey's (optimum) location through an iterative procedure [15-18].
Similar to the social hierarchy of grey wolves, there are four groups defined in GWO algorithm namely; Alpha (α), Beta (β), Delta (δ), and Omega (ω).The α presents the fittest solution and it is followed by β and δ as the second and third best solutions, respectively. The rest of the solutions are considered as ω which are least important. The process of the GWO technique completes in four steps; encircling the prey, hunting, attacking the prey (exploration process) and searching the prey; exploration capability.
The functions of each group have also been defined in Figure 3 [16, 20].

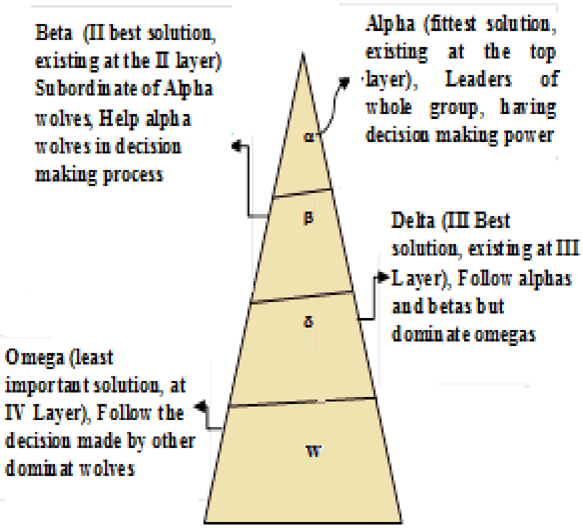

Figure 3: Social hierarchy of GWO with functions of each group

Two main parameters are initialized before starting the GWO. The first parameter is the "maximum number of search agents (*SA*)" or "grey wolves". The second important parameter is the "number of iterations (*Iter*)". These two parameters may vary according to the application. In present research work, the parameters used for simulation of the GWO algorithm are given in Table 1.

Table1: Parameters used for the GWO algorithm with IAE objective function

Parameter	Value
Number of Search Agents	30
Dimension	3
Maximum Iterations	50
Lower Bounds	[0.0001 0.0001 0.0001]
Upper Bounds	[20 20 20]

5. IMPLEMENTATION OF GWO/PID APPROACH

The complete Simulink model of the BH systems with IAE objective functions is shown in Figure 4.

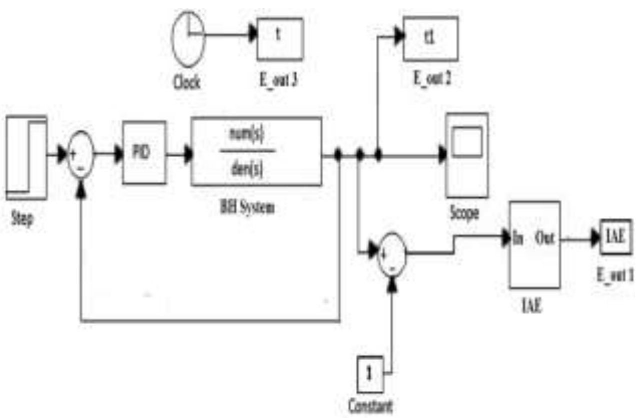

Figure 4: Complete simulink model of BH system with PID controller and IAE objective function

The GWO algorithm has been run in Matlab for the simulink model shown in Figure 4 and obtained parameters of PID controller are given by:

$$K_P = 4.9900; \quad K_I = 0.0010; \quad K_D = 5.7056 \qquad (4)$$

Therefore, the PID controller is given by:

$$G_C = 4.9900 + \frac{0.0010}{s} + 5.7056s \qquad (5)$$

The closed loop transfer function of the BH system with a PID controller and unity feedback is given by:

$$G_{CL}(IAE) = \frac{5.7056s^2 + 4.9900s + 0.0010}{s^5 + 6s^4 + 11s^3 + 11.7056s^2 + 4.9900s + 0.0010} \qquad (6)$$

In Table 2, the parameters of PID controller obtained by other existing techniques in literature for the same BH system have been given.

Table 2: Parameters of PID controller for BH system obtained by DE_{chaos}, $SOMA_{chaos}$, Z-N, CPSO and GWO

Algorithm	IAE		
	K_P	K_I	K_D
CPSO [10]	5.8653	0.0001	11.4188
Z-N [10]	6	1.9078	4.7178
$SOMA_{chaos}$ [14]	5.856	0.0043	11.835
DE_{chaos} [14]	5.856	0.0043	11.835
GWO (Proposed)	**4.9900**	**0.0010**	**5.7056**

6. COMPARATIVE ANALYSIS

In Table 3, different closed loop transfer functions of the BH system for the proposed and other existing techniques have been calculated, as per the parameters of PID controller given in Table 2. Based on these closed loop transfer functions, the responses of the GWO/PID approach for the BH system with other existing techniques have been compared in Figure 5.

Table 3: Comparison of the GWO/PID (IAE) approach with other existing techniques

Algorithm	Closed loop transfer function (G_{CL})
Z-N [10]	$\frac{4.7178s^2 + 6s + 1.9078}{s^5 + 6s^4 + 11s^3 + 10.7178s^2 + 6s + 1.9078}$
CPSO [10]	$\frac{11.4188s^2 + 5.8653s + 0.0001}{s^5 + 6s^4 + 11s^3 + 17.4188s^2 + 5.8653s + 0.0001}$
DE_{Chaos} [14]	$\frac{11.835s^2 + 5.856s + 0.0043}{s^5 + 6s^4 + 11s^3 + 17.835s^2 + 5.856s + 0.0043}$
GWO (Proposed)	$\frac{5.7056s^2 + 4.9900s + 0.0010}{s^5 + 6s^4 + 11s^3 + 11.7056s^2 + 4.9900s + 0.0010}$

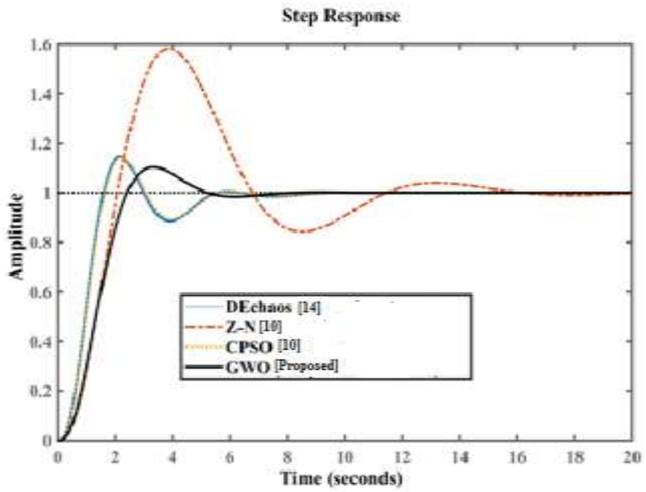

Figure 5: Comparison of GWO/PID (IAE) approach with existing techniques for BH system

It can be seen in Figure 5 that, GWO/PID approach with IAE gives less overshoot and settling time in comparison to existing approaches in the literature.

In Table 4, comparative analysis of proposed GWO/PID scheme with other existing approaches has also been shown in terms of settling time. It can be seen in Table 4 that, the proposed GWO/PID approach gives less settling time in comparison to existing techniques. In Figure 6, the settling time comparison has also been shown in bar graph form.

Table 4: Settling time comparison with the existing techniques of the GWO/PID (IAE) approach for the BH System

Algorithm/Controller	Settling Time
DE_{chaos} [14]	5.19
$SOMA_{chaos}$ [14]	5.19
Z-N [10]	10.6
CPSO [10]	4.88
Standard PSO [11]	7.2
AHPSO Global [11]	7.58
AHPSO Local [11]	5.1
GWO (Proposed)	**4.8**

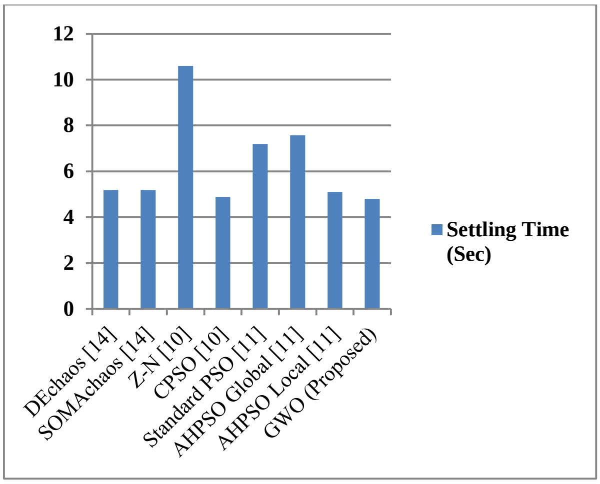

Figure 6: Bar chart comparison of settling time for BH system with IAE objective function

In Table 5, comparative analysis of proposed GWO/PID scheme with other existing approaches has also been shown in terms of overshoot. It can be seen in Table 5 that, the proposed GWO/PID approach gives less overshoot in comparison to existing techniques. In Figure 7, the settling time comparison has also been shown in bar graph form.

Table 5: Overshoot comparison with the existing techniques of the GWO/PID (IAE) approach for the BH System

Algorithm/Controller	Overshoot (%)
Z-N [10]	58.4
CPSO [10]	14.6
Standard PSO [11]	25
AHPSO Global [11]	15.5
AHPSO Local [11]	14
DE_{chaos} [14]	14.5
$SOMA_{chaos}$ [14]	14.5
GWO (Proposed)	**10.4**

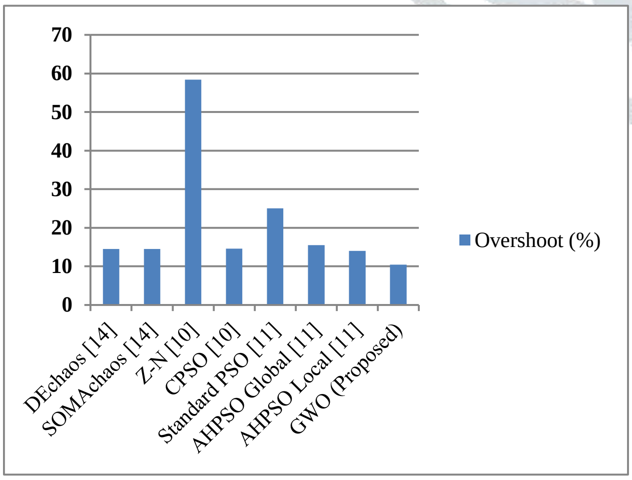

Figure 7: Bar chart comparison of overshoot for BH system with IAE objective function

7 CONCLUSIONS

The application of GWO algorithm in control of ball hoop system has been shown. The IAE has been taken as an objective/fitness function. Comparison of proposed GWO/PID scheme with IAE has also been shown with other existing techniques; such as Z-N [10], CPSO [10] and DE_{chaos} [14], etc. The simulation results reveal that GWO/PID scheme with IAE as an objective function gives less value of overshoot and settling time in comparison to other existing approaches.

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