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Application of GWO in Control of BH System with ISE Objective Function

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Abstract— This work deals with performance evaluation of integral square error (ISE) objective function in determining the optimal parameters of proportional-integral-derivative (PID) controller for control of ball hoop system using Grey Wolf Optimization (GWO) algorithm. The GWO is recently proposed bio inspired heuristic algorithm inspired by both the social hierarchy and hunting strategy of grey wolves. Comparison of proposed GWO/PID scheme with other existing techniques has also been shown in graphical and tabular forms. It has been observed that proposed GWO/PID approach with ISE as an objective function gives less settling time and overshoot when compared with existing approaches in the literature.

Keywords— Ball Hoop System, PID Controller, Grey Wolf Optimization, Meta-Heuristic, Integral Square Error (ISE).

I. INTRODUCTION

From several years the proportional-integral-derivative (PID) controllers are the most widely used controllers in process industries. Three parameters of PID controller are proportional gain (KP), integral gain (KI) and derivative gain (KD) [1-3]. The adjustment of these three parameters to achieve the desired response is called tuning of the PID 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]. Presently due to increase of complexity of processes in plants some challenges arises regarding tuning of PID controller parameters for achieving stability and good transient performance. 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 [6-8].

To tune the parameters of PID controllers for ball hoop system various meta-heuristic algorithms are already available in the literature such as; Genetic Algorithm (GA) [8], Particle Swarm Optimization (PSO) [9], Chaotic Particle Swarm Optimization (CPSO) [10], Adaptive Hybrid PSO (AHPSO) [11], Chaos driven Differential Evolution algorithm (DEChaos) and Self-Organizing Migrating

Algorithm (SOMAchaos) [12], Artificial Bee Colony Optimization (ABC) [13] and Bacterial Foraging Optimization (BFO) [13-14], etc.

The present work deals with tuning the parameters of PID controller for control of ball hoop system with ISE as an objective function using GWO algorithm. The 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), these wolves estimate the location of prey's (optimum) through an iterative procedure.

II. BALL HOOP SYSTEM

The construction of ball hoop system (BH system) is easy, due to its good dynamics it is preferred by control engineers for research. 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 considerable because the movement of large quantities of liquid can strongly influence the movement of the container itself, which is usually undesirable and often dangerous [7-13], as shown in Fig. 1.

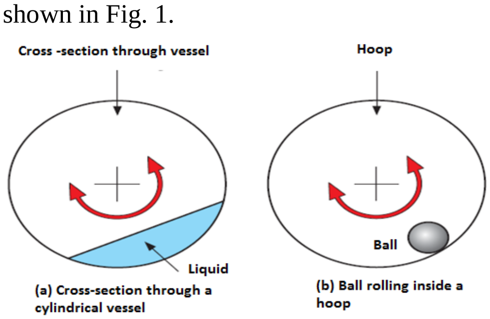

Figure 1: Liquid analogy of ball hoop system

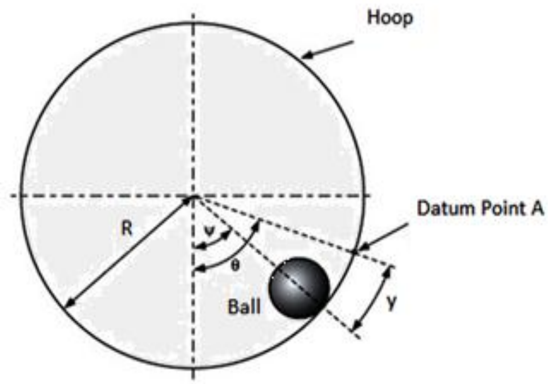

Figure 2: Ball hoop system

Figure 2 shows a schematic of the BH system which is a 4th order system [11]. 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 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, 23]:

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

In present work, equation (1) has been obtained by linearizing the BH system equations given in [14, 23].

III. 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 (2), the three important parameters of PID controllers are proportional gain (Kp), integral constant (Ki) and derivative constant (Kd).

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 parameters (Kp, Ki, Kd) of the PID controller are tuned by GWO algorithm with ISE objective function.

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

$$ISE = \int_0^\infty e^2(t)\, dt \quad (3)$$

The simulink model of ISE using Matlab is shown in Figure 3.

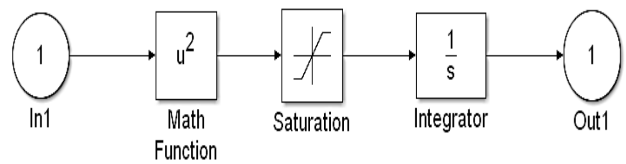

Figure 3: Simulink model representation of ISE

IV. GREY WOLF OPTIMIZATION

The GWO has recently been proposed bio inspired heuristic algorithm inspired by both 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].

The functions of each group are as follows:

- The leaders are a male and female, called alphas. The alpha is mostly responsible for making decisions about hunting, sleeping place, time to wake, and so on. The alpha's decisions are dictated to the pack. Interestingly, the alpha is not necessarily the strongest member of the pack but the best in terms of managing the pack. This shows that the organization and discipline of a pack is much more important than its strength.
- The second level in the hierarchy of grey wolves is beta. The betas are subordinate wolves that help the alpha in decision-making or other pack activities.
- The lowest ranking grey wolf is omega. The omega plays the role of scapegoat. Omega wolves always have to submit to all the other dominant wolves. If a wolf is not an alpha, beta, or omega, he/she is called subordinate (or delta in some references).
- Delta wolves have to submit to alphas and betas, but they dominate the omega. Scouts, sentinels, elders, hunters, and caretakers belong to this category.

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 4 [15-16, 23].

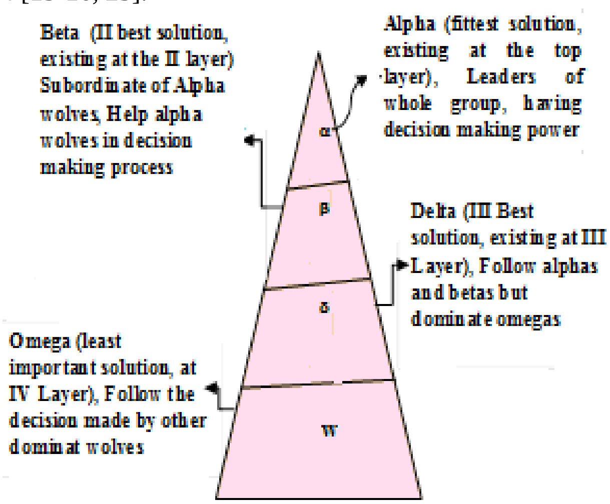

Figure 4: Social hierarchy of GWO and functions of each group [15, 23]

The flow chart representation of the GWO is shown in Figure 5. The flow chart describes each stage performing the whole process.

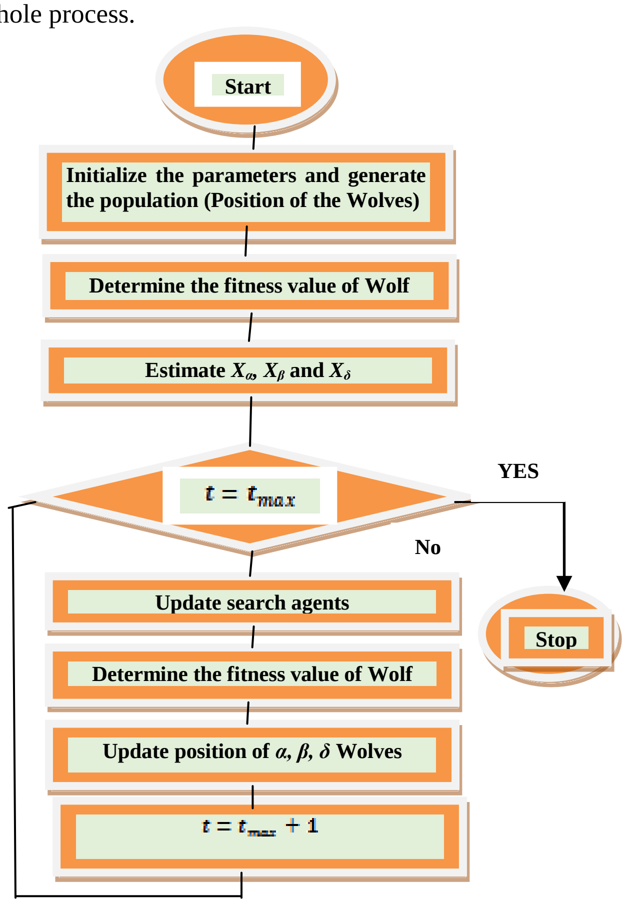

Figure 5: Flow chart of GWO algorithm [23]

Two main parameters of GWO are "maximum number of search agents (*SA*)" or "grey wolves" and "number of iterations (*Iter*)", these should be initialized before starting the GWO. According to application these two parameters may vary. In present research work, the GWO initial parameters used for simulation are given in Table 1.

Table 1: Parameters used for the GWO algorithm with ISE objective function

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

V. IMPLEMENTATION OF GWO/PID APPROACH

The complete Simulink model of the BH systems with ISE objective functions is shown in Figure 6.

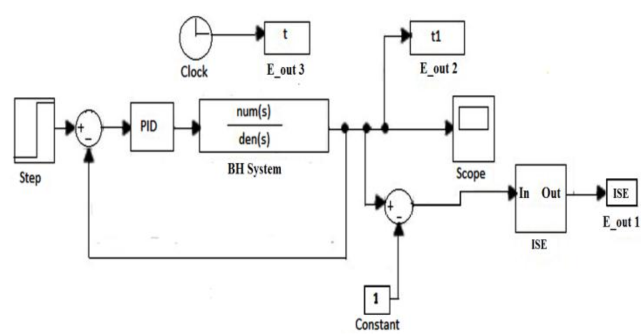

Figure 6: Complete simulink model of BH system with PID controller and ISE objective function

The GWO algorithm has been run in Matlab for the simulink model shown in Figure 6 and obtained parameters of PID controller are given by:

K_P= 6.9860; K_I= 0.0018; K_D=9.0671 (4)

Therefore, the PID controller is given by:

$$G_C = 6.9860 + \frac{0.0018}{s} + 9.0671s \quad (5)$$

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

$$G_{CL}(ISE) = \frac{9.0671s^2 + 6.9860s + 0.0018}{s^5 + 6s^4 + 11s^3 + 15.0671s^2 + 6.9860s + 0.0018} \quad (6)$$

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}, $SOMA_{chaos}$ and GWO

Algorithm	ISE		
	K_P	K_I	K_D
DE_{chaos} [12]	5.204	0.1568	20.804
$SOMA_{chaos}$ [12]	5.204	0.1568	20.804
GWO (Proposed)	**6.9860**	**0.0018**	**9.0671**

VI. 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 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 7.

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

Algorithm	Closed loop transfer function (G_{CL})
DE_{Chaos} [12]	$\frac{20.804s^2 + 5.204s + 0.1568}{s^5 + 6s^4 + 11s^3 + 26.804s^2 + 5.204s + 0.1568}$
$SOMA_{chaos}$ [12]	$\frac{20.804s^2 + 5.204s + 0.1568}{s^5 + 6s^4 + 11s^3 + 26.804s^2 + 5.204s + 0.1568}$
GWO (Proposed)	$\frac{9.0671s^2 + 6.9860s + 0.0018}{s^5 + 6s^4 + 11s^3 + 15.0671s^2 + 6.9860s + 0.0018}$

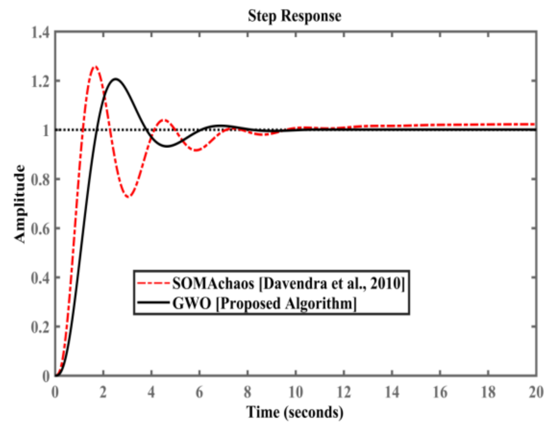

Figure 7: Comparison of GWO/PID (ISE) approach with existing techniques for BH system

The comparison of control of BH system with other existing approaches has been shown in Figure 7. It can be seen in Figure 7 that, GWO/PID approach with ISE gives low values of overshoot and settling time in comparison to existing approaches in the literature.

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

Algorithm	Settling Time (Sec)
DEchaos [12]	9.22
SOMAchaos [12]	9.22
Standard PSO [11]	9.54
AHPSO Global [11]	9.29
AHPSO Local [11]	9.14
GWO (Proposed)	5.68

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 low value of settling time in comparison to existing techniques. In Figure 8, the settling time comparison has also been shown in bar graph form.

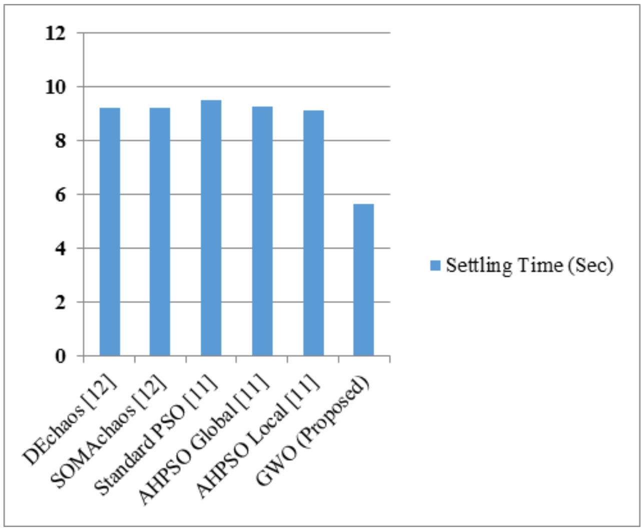

Figure 8: Bar chart comparison of settling time for BH system

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 low value of overshoot in comparison to existing techniques. In Figure 9, the overshoot comparison has also been shown in bar graph form.

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

Algorithm	**Overshoot (%)**
DE_{chaos} [12]	24.52
$SOMA_{chaos}$ [12]	24.52
Standard PSO [11]	25.95
AHPSO Global [11]	28
AHPSO Local [11]	25.89
GWO (Proposed)	**20.6**

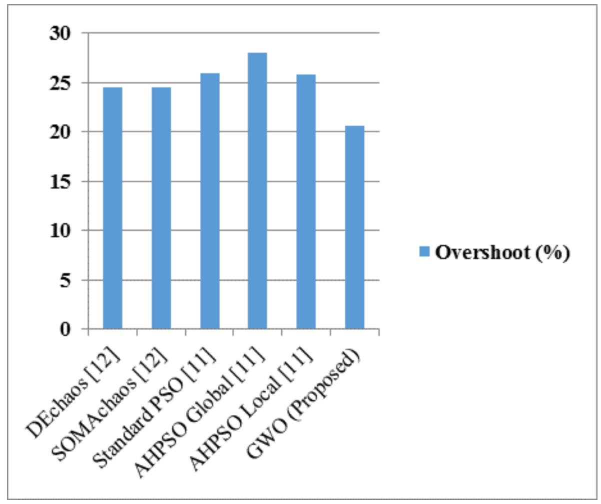

Figure 9: Bar chart comparison of overshoot for BH system

VII. CONCLUSIONS

The application of GWO/PID approach in control of ball hoop system has been shown. The ISE has been taken as an objective function. In Tables 4-5, comparison of proposed GWO/PID scheme with ISE as an objective function has also been shown with other existing techniques; such as DEchaos [12], SOMAchaos [12], Standard PSO [11], AHPSO Global [11] and AHPSO Local [11], etc. The simulation results reveal that GWO/PID scheme with ISE as an objective function gives low value of overshoot and settling time when compared with existing approaches.

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