GREY WOLF OPTIMIZATION BASED CONTROLLER DESIGN FOR A TWO TANK SYSTEM

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Abstract

Most of the optimization techniques in general lead to slow convergence and scant accuracy due to the non-linear behavior of the system. One such nonlinear behavior that acts as a benchmark for control problem is an interacting two-tank system. The two-tank system is a classic example of a control system with a Single Input Single Output (SISO) configuration, where the objective is to regulate the level of water in the second tank by manipulating the flow rate between the two tanks. Meta-heuristic algorithms provide the optimal solution by considering all possible ways for a control problem. In this paper, a modern meta-heuristic optimization algorithm called as Grey Wolf Optimizer (GWO) algorithm is used for obtaining the most feasible solution of a Single Input Single Output (SISO) interacting two-tank system for controlling the liquid level. The GWO algorithm is inspired by the social behavior of grey wolves, which specially focus on their leadership hierarchy as well as in their hunting behavior. GWO algorithm is best suited to obtain the controller parameters to achieve the desired performance in which an optimal solution can be obtained for the effective control of the liquid level in the two-tank system. GWO algorithm is implemented to achieve the desired time integral performance criteria to minimize the integral square error by tracking the set point and disturbances that affects the process. MATLAB SIMULINK software is used to implement the GWO algorithm to optimize the controller parameters of an interacting SISO two tank system.

Keywords: Interacting two tank system, Controller parameters, Integral square error, Single Input Single Output system, Grey Wolf Optimizer.

1. Introduction

In general, any system consisting of appropriate inputs and outputs falls under one of the below mentioned multi variable systems viz. a) single input single output (SISO) system that gets input from one sensor and controls only one parameter, b) single input multiple output (SIMO) system that gets input from one sensor and controls multiple parameters, c) multiple input single output (MISO) system that gets input from multiple number of sensors and controls only one parameter and d) multiple input multiple output (MIMO) system that gets input from multiple sensors and controls multiple parameters. The major advantage of a SISO system lies in its characteristics of possessing less complexity and it acts as a benchmark for the design of complex controllers. When designing a SISO controller, two major points are to be kept in mind. First one is for what types of manipulated variables the controlled variable can be set; that is termed as a variable pairing problem. Secondly, it should be clear what type of tuning methods are to be implemented in order to get the required controller parameters. By specifying the controller parameters and reset time the overall stability of the system (SISO) can be improved.

There is a great demand for liquid level control in pharmaceutical industries, chemical industries, food industries, refilling processes etc. In these processes, liquid is pumped and stored in a tank and then transferred to another tank thereby emphasizing the need for controlling the liquid level. Increase in the quality of control leads to process efficiency or increased production, due to the reduction in production cost. While controlling such fluid level in interacting two-tank system, the major challenges encountered are non-linearity and uncertainty of the system.

Controller parameters can possibly affect the product quality owing to more nonlinearities present in the system [1] eventually playing a major role in any process industry. The authors have made use of Biggest Log Modulus Tuning (BLT) method to construct a decentralized PI controller for a coupled tank process considering the interactions. The control of the liquid level in SISO interacting two-tank system [2] is one such process industrial applications that invites attention. Over the past few decades' conventional tuning methods [3] have been used to obtain the controller parameters. In the recent years' controller parameters are being obtained by using artificial intelligence techniques (AI) [4]. In this work, we have used one of the most prominent AI technique called GWO algorithm in order to obtain the desired controller parameters [5].

Most of the studies are seen to design a controller by obtaining a linear mathematical model. Some of them are fuzzy-PID controller [6], decentralized PI controller [7], Fractional order PI- PD controller [8]. Some others address the nonlinearity of the system and design a nonlinear controller such as back stepping control [9],Neuro-fuzzy sliding Mode Controller [10] etc.

2. Description of process

The Single Input Single Output (SISO) Two Tank System as depicted in Fig.1 is a classic control system example that involves regulating the level of water in a second tank by manipulating the flow rate between two tanks. This system is commonly used as a benchmark problem in control engineering, and it can be analysed using a range of control strategies, including model-based and feedback control.

The two-tank system consists of two interconnected tanks, where water flows from one tank to the other. The objective of the control system is to regulate the level of the second tank by manipulating the flow rate between the two tanks.

An identical pair of tanks coupled each other that emulates a SISO system is seen in Fig.1. In this system the input is the flow rate of first tank F_{in} that is a manipulated variable which depends on the supply voltage u(t) to the pump and the output is the liquid level of tank 2 i.e. the controlled variable. The outlet of the second tank's flow rate is considered as F_{out}. The interaction between the two tanks is through a pipe with cross-sectional area a_{12} and the outlet pipe of the second tank is considered to be as a_2.

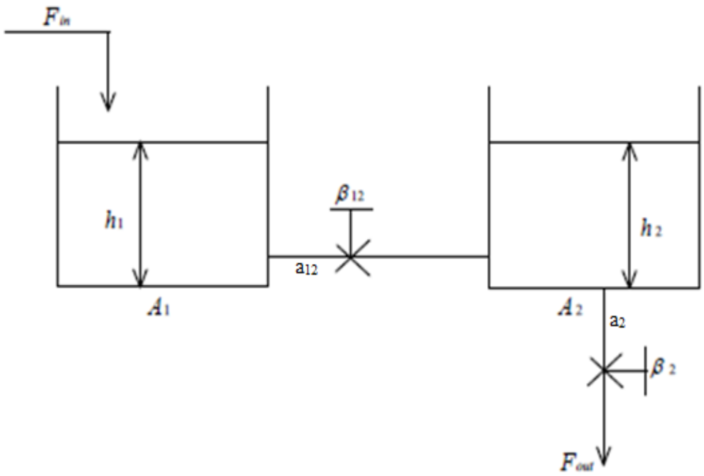

Fig.1. Interacting two-tank SISO system

The variables,

h_1, h_2 - Liquid levels of tank 1 and 2 respectively

A_1, A_2 - cross-sectional areas of tank 1 and 2 respectively.

β_{12}, β_2 - Valve ratios of intermediate valve between the tanks and valve at tank 2 outlet

K - Pump Gain

g - Earth gravity

Mathematically, the above interacting two-tank SISO system can be represented in the differential form as follows.

$$\frac{dh_1(t)}{dt} = -\frac{\beta_{12}a_{12}}{A_1}\sqrt{2g(h_1(t) - (h_2(t))} + \frac{K}{A_1}u(t) \quad \ldots. \quad (1)$$

$$\frac{dh_2(t)}{dt} = -\frac{\beta_2 a_2}{A_2}\sqrt{2g(h_2(t))} + \frac{\beta_{12}a_{12}}{A_1}\sqrt{2g(h_1(t) - (h_2(t))} \quad \ldots. \quad (2)$$

3. METAHEURISTIC ALGORITHMS

Metaheuristic algorithms are a class of optimization algorithms used to determine the best possible solution out of all the available solutions. Metaheuristic algorithms [11] use search strategies to find solutions to optimization problems. These algorithms are particularly useful for solving complex optimization problems with multiple constraints and objectives. They can be used to tune the controller parameters and achieve effective regulation of the water level in the second tank of the interacting Two Tank System.

Some of the most common metaheuristic algorithms used for optimizing the SISO Two Tank System include: Genetic Algorithm (GA) that simulates the natural selection process [4], Particle Swarm Optimization

(PSO) which simulates the social behaviour of a group of particles [12], Ant Colony Optimization (ACO) that simulates the foraging behaviour of ants in finding the shortest path to a food source [13], Simulated Annealing (SA) a metaheuristic algorithm that simulates the annealing process in metallurgy to find the optimal solution [14], Firefly Algorithm (FA) that is inspired by the flashing behaviour of fireflies [15], Bat Algorithm (BA) which is inspired by the echolocation behaviour of bats [16], Harmony Search Algorithm (HS) that is inspired by the process of musicians harmonizing to find the optimal melody [17], Artificial Bee Colony (ABC) algorithm inspired by the behaviour of honeybees in a colony [18] etc. The objective behind such metaheuristic algorithms is to tune the controller parameters and find the optimal valve position that will regulate the flow rate of water between the two tanks and maintain the desired water level in the second tank.

These algorithms are popular because of their easiness, flexibility and even these offer derivation free mechanism. The base for the Swarm Intelligence (SI) techniques are generally obtained from natural colonies like ants (ACO), flock (Starling PSO, a variant of Particle Swarm Optimization (PSO) algorithm inspired by the flocking behaviour of birds) [19], herds (Herd Optimization Algorithm (HOA) which mimics the movement of a herd of herbivorous animals towards food sources or water) [20], tusker (Elephant Optimization Algorithm (EHO) that mimics the movement of an elephant herd towards food sources and water) [21] etc. These algorithms can provide an efficient and effective way to optimize the performance of the SISO Two Tank System and can possibly be applied to a wide range of control system problems.

3(a). Grey Wolf hierarchy

Scientifically wolves can be referred as Canis Lupus. In Latin, Lupus means wolf and Canis means dog. Grey wolves originate from Canidae family and are positioned at the crest of food chain. These Grey wolves generally live as a group i.e., pack. On an average, the pack size can differ from 5 to 12 members. The pack follows strictly the social hierarchal position as shown in Fig. 2.

The leaders at the topmost of the pyramid named as alpha can be either a male or a female. This alpha is responsible for taking all kind of decisions in a pack like hunting, duration of sleep, path to follow and so on. These decisions are to be followed by rest of the pack, so alpha wolf is referred as dominant member in the pack. If a wolf has more managing skills irrespective of its physical stamina such a wolf is chosen as alpha wolf.

The immediate subordinate of alpha wolf is beta wolf, which can be either a male or a female. It is positioned as second level in the hierarchy of grey wolves. It helps alpha wolf in making decisions that are related to the pack. Beta has all the qualities to become future alpha in case like alpha becomes old or passes away. It acts as adviser to alpha and is responsible to maintain strict discipline within the pack. The beta spreads the alpha's commands to the pack and collects feedback from pack, which are then transferred to the alpha.

Fig.2. Hierarchy of Grey Wolf

The subordinate of alpha wolf and beta wolf is called as delta wolf. Delta wolf can be either a male or female. It is located in level three of grey wolf hierarchy. It needs to follow instructions given by both the alpha and beta wolves. Based upon the role these delta wolves are of five types. They are scouts, sentinels, elders, hunters, and caretakers. Scouts are those who look over the boundaries of the territory in search of a pray and they warn the rest of pack in case of any emergency. Sentinels are responsible for protection and safety of the pack. Experienced wolves termed as Elders, help alpha and beta in decision-making. Hunters are the one who helps the pack in hunting the prey and they provide food for entire pack. Lastly, caretakers are those who are responsible for taking care of the weak, wounded and ill wolves in the pack.

The least level of grey wolf is omega. Omega wolf need to obey the commands given by all the other three dominant wolves in the pack. They have the least priority in the pack and are the one allowed to eat at last.

3(b). Grey Wolf Optimization (GWO) hunting mechanism

The GWO algorithm is a population-based optimization method that mimics the hunting behaviour of grey wolves in the wild [5]. The algorithm starts by initializing a population of grey wolves with random positions in the parameter space. The fitness of each grey wolf in the population is evaluated based on the performance of the control system with the corresponding parameter values. The alpha, beta, and delta wolves in the population are then selected based on their fitness values, with the alpha wolf having the best fitness value, followed by the beta and delta wolves as represented in Fig.2.

Apart from the social hierarchy of grey wolf, other special attractive behaviour is hunting mechanism. Different phases of hunting mechanism are encircling, hunting, attacking and searching the prey.

(a) Encircling prey

After identification of a prey, hunting mechanism starts by encircling the prey from all sides. Mathematically the encircling mechanism can be represented as follows.

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \qquad \ldots\ldots. \quad (3)$$

$$\vec{X}(t+1) = \vec{X}_P(t) - \vec{A} \cdot \vec{D} \qquad \ldots\ldots \quad (4)$$

In the equations (3) and (4), t represents the present iteration, $\vec{X}$ is grey wolf position vector, $\vec{X}_P$ is the position vector of the prey. $\vec{A}$ and $\vec{C}$ are the coefficient vectors which can be summarized by the following two equations.

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \qquad \ldots. \quad (5)$$

$$\vec{C} = 2 \cdot \vec{r}_2 \qquad \ldots. \quad (6)$$

In the equations (5) and (6) vector$\vec{a}$ isa value that linearly decreasesfrom 2 down to 0 during theiterative process.The vectors $\vec{r}_1$ and $\vec{r}_2$ are the random values in the range [0, 1].

(b) Hunting prey

The general hunting process is guided by alpha that are to be followed by beta and delta. Mathematically we initialize by assuming alpha, beta and delta have better knowledge about the position of a prey. Therefore, we save the first best three solutions as alpha, beta and delta. This process will be continued to update their next best positions based on the position of search agents. Mathematically this is given as follows:

$$\vec{D}_\alpha = |\vec{C}_1 \cdot \vec{X}_\alpha - \vec{X}|, \vec{D}_\beta = |\vec{C}_2 \cdot \vec{X}_\beta - \vec{X}|, \vec{D}_\delta = |\vec{C}_3 \cdot \vec{X}_\delta - \vec{X}| \quad \ldots. \quad (7)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 \cdot (\vec{D}_\alpha), \vec{X}_2 = \vec{X}_\beta - \vec{A}_2 \cdot (\vec{D}_\beta), \vec{X}_3 = \vec{X}_\delta - \vec{A}_3 \cdot (\vec{D}_\delta) \quad \ldots. \quad (8)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad \ldots. \quad (9)$$

(c) Attacking prey

When the prey is unable to take a step (stops moving any further) the grey wolf stops hunting process by attacking the prey. In mathematical model, prey position can be analysed based on the value of $\vec{A}$which is a function of $\vec{a}$. As $\vec{a}$ value ranges from 1 to 0, $\vec{A}$varies from 2 to 0. In the iterative process if $|A| < 1$it means the prey position is stopped, this situation forces the grey wolves to attack the pray which means the most feasible solution has been obtained and the process may end by this.

(d) Search for prey

The pack of grey wolf searches the prey based upon the positions of alpha, beta and delta. The members of the pack diverge each other in search of a prey and they converge in the process of attacking the prey. If prey is strong enough, then it will move against the pack. This means grey wolves cannot stop the prey. Mathematically this can be identified by vector $\vec{A}$. The condition $|A| > 1$ means the prey position cannot be stopped, and this situation forces the grey wolves to diverge from the prey and they begin to search for another prey.

The GWO algorithm proposed by [22] iteratively repeats the evaluation and update steps until a termination criterion is met, such as a maximum number of iterations or a minimum error threshold. The flow chart of GWO algorithm is represented in Fig.3.

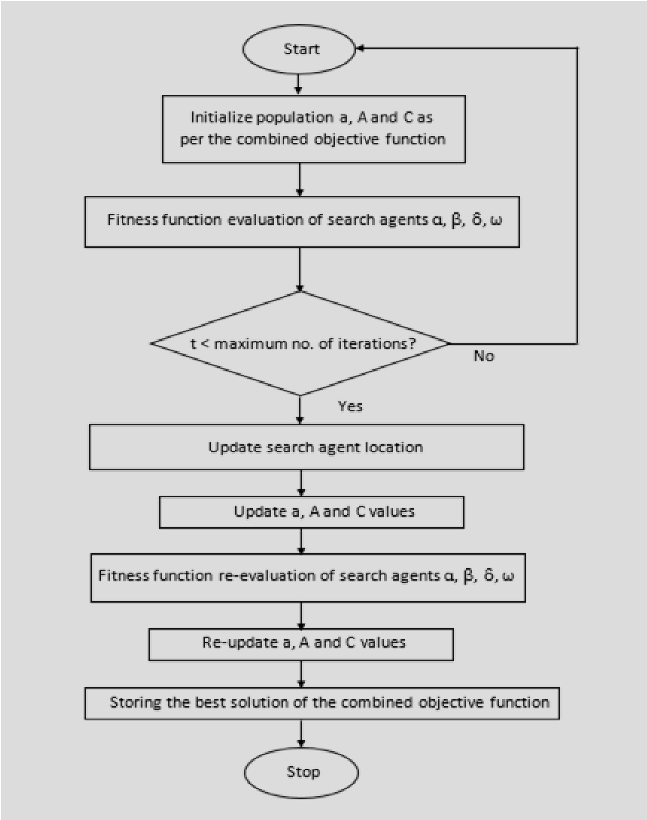

Fig. 3 GWO Algorithm flow chart

4. Simulation Results

In the context of the two-tank system, the goal is to find the optimal values of the controller parameters that can regulate the level of water in the second tank. GWO has been used to search the parameter space and find the optimal solution. The fitness function used in the two-tank system is typically the Integral of the Absolute Error (IAE) or Integral of the Squared Error (ISE) between the desired and actual level of water in the second tank over a specified time horizon.

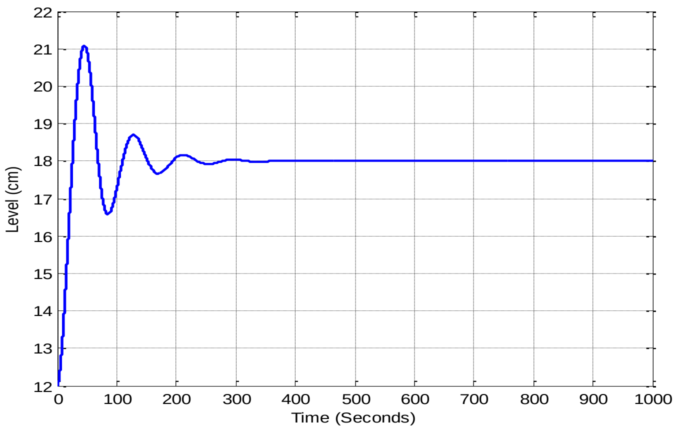

Fig. 4. Set point change in Tank2 from 8 – 18 cms

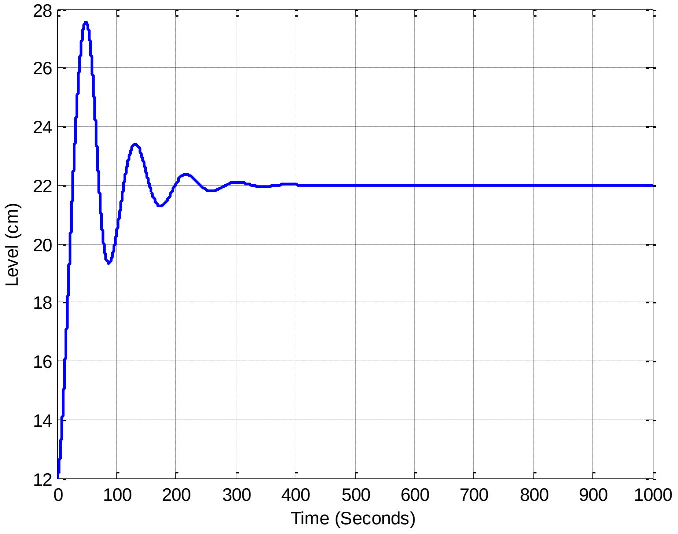

Fig. 5. Set point change in Tank2 from 12 – 22 cms

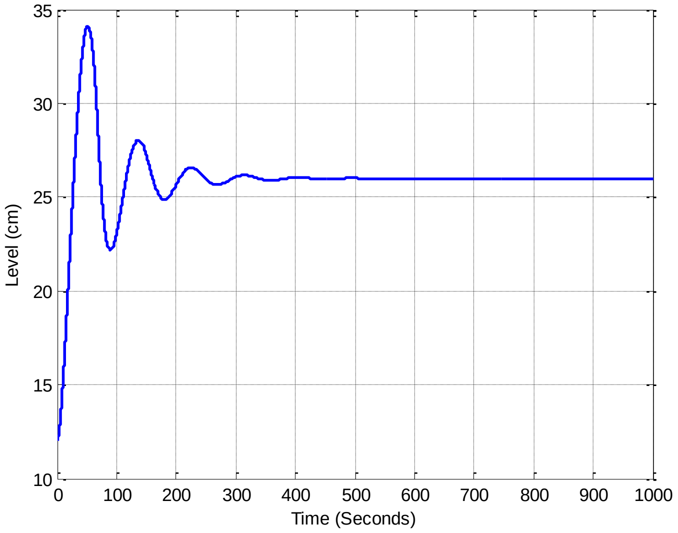

Fig. 6. Set point change in Tank2 from 16 – 26 cms

The set point changes effected in Tank 2 and the response of the GWO optimized control algorithm in attaining set point tracking is presented in the above figures (Fig. 4, 5, 6) and the performance indices of the same is provided in Table 1. The significant improvement in performance is evident when compared to the conventional control strategies as adopted in [2]

Table 1. Performance Measure of GWO algorithm

Set point change in Tank2					
	ISE	**IAE**	**Rise Time (Sec)**	**Peak overshoot (cm)**	**Settling time (Sec)**
08 – 18 cm	662.9	246	24.6	16.67	310
12 – 22 cm	2052	460.5	26.6	29.58	330
16 – 26 cm	4342	694.1	28	31.15	380

5. Conclusion

The GWO algorithm is a definitely powerful and efficient optimization method that can be applied to a wide range of control problems, including the two-tank system. By using the GWO algorithm, we have optimized the PI controller parameters of the interacting two-tank system and an improvement in its performance in regulating the level of water in the second tank is witnessed. By selecting an appropriate control strategy and tuning the controller parameters, effective regulation of the water level in the second tank of the Two Tank System is achieved.

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