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APPLICATION OF BINARY FIREFLY ALGORITHM (BFA) IN TUNING PID PARAMETERS FOR COUPLE TANK SYSTEM

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ABSTRACT

This paper presents the application of the Binary Firefly Algorithm (BFA) in tuning PID parameters for a coupled tank system. The agent position in the BFA represents the potential combination the PID parameters. This agent position is modelled using a string of 32 binary bits where each eight bits represents the value of Kp, Ki, and Kd, respectively. Represents the values of PID parameters. The first five bits represents the decimal value while the remaining are fraction value. The model of the coupled tank system is taken from well-established literature. The proposed approach is then implemented on the model that used a PID controller as the control mechanism. This study proposed a priority based fitness formulation where the agent will give priority to the following parameters in the given order: 1) Sum of Absolute Error (SAE); 2) Overshoot (OS); 3) Settling Time (ST), and Steady-State Error (SSE). The result discussed the effect of number of agent and number of iterations towards the performance of the proposed approach.

Keywords: optimization, computational intelligence, binary firefly algorithm, PID controller, couple tank system.

1. INTRODUCTION

A typical Coupled Tank System (CTS) is as shown in Figure-1 where the tank system is the combination of two liquid tanks [1]. The construction of CTS might seem simple yet it had been widely installed in industrial applications such as in petrochemical, papermaking, and water treatment industries [2]. The control of the liquid in the tank and flow of the liquid between tanks is the common problem of the tank system in the industries. The liquids will be processed by chemical or mixing treatment most of the time, but the level of the fluid must be controlled all of the time and the flow between tanks must be regulated.

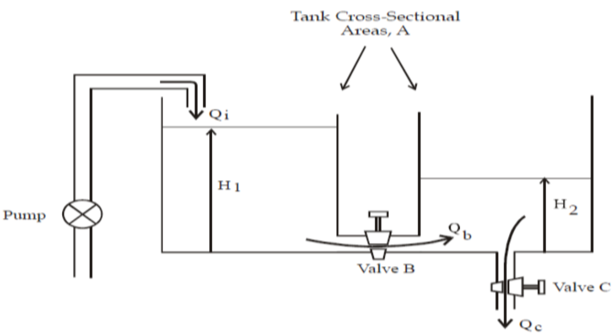

Figure-1. Coupled tanks system.

The most widely used controller in industrial process control is the Proportional-Integral-Derivative (PID) controller which normally has been applied to control the couple tanks system [1] [3]. A PID controller provides a control loop feedback function where it calculates the error by comparing the measured results with the desired set point and minimizes the errors by adjusting the input values. The three parameters of the PID controller which are Proportional Gain (Kp), Integration Gain (Ki) and Derivative Gain (Kd) can provide control action designed for specific process requirements [4][5].

Although a PID controller can detect error and adjusting to reduce the error, it does not guarantee the best performance of the system nor the system stability due to the selection of PID parameters [4].

The Binary Firefly Algorithm (BFA) is an extension of the Firefly Algorithm which is a metaheuristic algorithm introduced by Xin-She Yang in the year 2007 [6]. This algorithm is inspired by the flashing behavior of the firefly[7]. The main purpose of the firefly's flash is to attract other fireflies. This matting behavior is adapted to be an optimization algorithm that is proven by the author [5] to be successful in tackling benchmark mathematical optimization problems [8].

The implementation of the optimization algorithm in controlling the PID controller for the CTS application is not uncommon. Ismail *et al*. [7] [9] proposed the application of two Swarm Intelligence algorithms: Particle Swarm Optimization (PSO) and Cuckoo Search in 2014 [6]. Hussien et al. proposed the priority-based PSO for tuning PID of CTS in the same year [1] [3].

2. METHODOLOGY

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The proposed model of CTS is a closed-loop system with the PID controller, which is illustrated in Figure-2 [1].

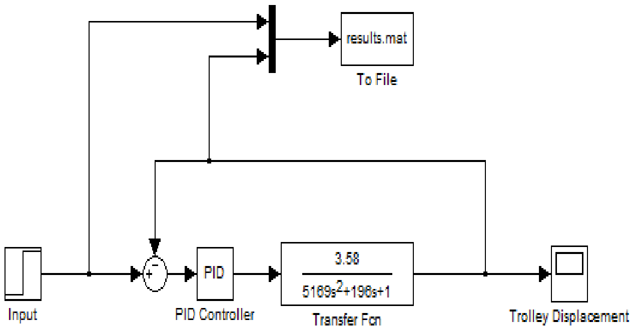

Figure-2. Couple tank system with PID controller.

The plant of the system is taken from [6] where the dynamics model of the tank system in s-domain can be written as:

$$\frac{H_2(s)}{V(s)} = \frac{3.58}{5169s^2+196s+1} \quad (1)$$

where V(s) and $H_2(s)$ are input voltage of the DC motor-driven pump and level of the second tank.

The proposed approach simulation is done using written M-file code. The M-file will automatically force simulation of the Simulink file as shown in Figure-2. The input and output signal of the simulation of the coupled tank will be recorded in a file. The BFA code that is run via M-file than access this file in order to calculate the fitness of the agent.

The algorithm of BFA is taken from [6]. The modelling of the proposed model is by using 8-bits to represent each of the PID parameter values of Kp, Ki, and Kd. Therefore, the location of a firefly in the search space is represented in 24 dimensions: each bit represented by one dimension. This can be expressed mathematically as in Eq. (2):

$$\boldsymbol{X} = [Kp\ Ki\ Kd]^{-1} \quad (2)$$

where $\boldsymbol{X}$ is the firefly position.

The first five bits represented the decimal value and the remaining three bits represent the fraction value of the parameter. Thus Kp can be express mathematically as in Eq. (3):

$$Kp = [b_{\mathrm{P1}}\ b_{\mathrm{P2}}\ b_{\mathrm{P3}}\ b_{\mathrm{P4}}\ b_{\mathrm{P5}}\ b_{\mathrm{P6}}\ b_{\mathrm{P7}}\ b_{\mathrm{P8}}] \quad (3)$$

where b_{P1} the most significant bit for decimal values and b_{P5} is the least significant bit for decimal value. While b_{P6} is the most significant bit for fraction value and b_{P8} is the least significant bit for fraction value. The same model applied to Ki and Kd as in Eq. (4) and Eq. (5):

$$Ki = [b_{\mathrm{I1}}\ b_{\mathrm{I2}}\ b_{\mathrm{I3}}\ b_{\mathrm{I4}}\ b_{\mathrm{I5}}\ b_{\mathrm{I6}}\ b_{\mathrm{I7}}\ b_{\mathrm{I8}}] \quad (4)$$

$$Kd = [b_{\mathrm{D1}}\ b_{\mathrm{D2}}\ b_{\mathrm{D3}}\ b_{\mathrm{D4}}\ b_{\mathrm{D5}}\ b_{\mathrm{D6}}\ b_{\mathrm{D7}}\ b_{\mathrm{D8}}] \quad (5)$$

Thus, the agent position can be rewritten as Eq. (4)

$$\boldsymbol{X} = \begin{bmatrix} b_{\mathrm{P1}}\ b_{\mathrm{P2}}\ b_{\mathrm{P3}}\ b_{\mathrm{P4}}\ b_{\mathrm{P5}}\ b_{\mathrm{P6}}\ b_{\mathrm{P7}}\ b_{\mathrm{P8}}\ b_{\mathrm{I1}}\ b_{\mathrm{I2}}\ b_{\mathrm{I3}}\ b_{\mathrm{I4}} \\ b_{\mathrm{I5}}\ b_{\mathrm{I6}}\ b_{\mathrm{I7}}\ b_{\mathrm{I8}}\ b_{\mathrm{D1}}\ b_{\mathrm{D2}}\ b_{\mathrm{D3}}\ b_{\mathrm{D4}}\ b_{\mathrm{D5}}\ b_{\mathrm{D6}}\ b_{\mathrm{D7}}\ b_{\mathrm{D8}} \end{bmatrix}^{-1} \quad (6)$$

The fitness model used is similar to the priority-based model proposed by [6] where the main priority is to minimize the sum of absolute error (SAE), the second priority is overshoot (OS), the third priority is settling time (ST) and last priority is a steady-state error (SSE).

3. RESULT AND DISCUSSIONS

The proposed BFA code is run in MATLAB. The code was run with different numbers of iterations and the number of agents. The higher number of the iteration or agent causing the more time combination will take to finish one cycle run. The number of iteration used were 10, 20, 30, 40, and 50 whilst the number of agent used were 5, 10, 15, 20, and 25 respectively. Each combination of the iteration and agent numbers ran five times per combination.

The overall result is tabulated in Table-1 and Table-2. There were 25 combination of parameters which based on different values of number of agent and iteration. Table-1 shows the average results of the BFA code run in the MATLAB based on the sum of absolute error (SAE), overshoot (OS), settling time (ST), and steady-state error (SSE). The average result in Table-1 was calculated from the five cycles run of each combination of the number of iteration and number of the agent.

Table-1. Average result for Sum Absolute Error (SSE), Overshoot (OS), Settling Time (ST) and Steady State Error (SSE).

Number of Agents	Fitness Model	Number of Iteration				
		10	20	30	40	50
5	SAE	7.51114	7.42828	7.39124	7.3138	7.08084
	OS	29.55132	24.97286	22.02984	18.26248	16.28782
	ST	4.69106	5.8084	5.89384	4.2754	4.12956
	SSE	0.00096	0	0.00404	0.01692	0.01732
10	SAE	7.38586	7.23016	7.32594	7.17066	7.09312
	OS	24.34824	22.26372	15.71012	11.22188	13.59774
	ST	5.03702	5.27286	4.84568	4.25918	4.90106
	SSE	0.00276	0.0043	0.00458	0.0206	0.00732
15	SAE	6.98082	6.89782	6.89852	6.55102	6.76116
	OS	14.39244	13.16908	14.04794	4.31536	9.59902
	ST	3.25694	4.36038	4.234	2.40488	3.48938
	SSE	0.021	0.0063	0.00522	0.02824	0.0209
20	SAE	6.89362	6.86558	6.38306	6.29894	6.747
	OS	11.92706	15.15866	7.05378	8.49334	8.13505
	ST	3.55944	5.076	2.90368	3.09868	2.83694
	SSE	0.01242	0.00174	0.01304	0.00376	0.02444
25	SAE	6.99108	6.91392	6.38316	6.4112	6.45912
	OS	15.34554	9.30388	4.86816	9.20486	8.3508
	ST	4.48918	3.7169	2.48766	3.09354	3.02648
	SSE	0.00674	0.01098	0.01354	0.02134	0.02724

Table-2. The minimum value for all results.

Number of Agents	Fitness Model	Number of Iteration				
		10	20	30	40	50
5	SAE	7.4224	7.4188	7.2552	6.9418	6.496
	OS	28.1517	18.148	12.3392	5.2657	9.5285
	ST	5.1893	7.1422	4.2403	2.59	3.4
	SSE	0	0	0.0202	0.0421	0.0272
10	SAE	7.204	6.4562	7.1614	6.3055	5.9585
	OS	7.5187	9.7079	0.027	6.6868	8.4088
	ST	3.3324	3.1947	2.7826	2.598	2.6201
	SSE	0.0138	0.0215	0	0	0
15	SAE	6.2623	5.8511	6.0278	5.7151	6.3187
	OS	13.4777	6.4762	8.5821	6.7802	4.145
	ST	3.6088	2.6119	2.6332	2.5534	2.5144
	SSE	0.0019	0.0084	0.0078	0.01	0.0241
20	SAE	6.629	5.839	5.7867	5.7867	6.3067
	OS	15.562	5.6321	4.6632	4.6332	6.661
	ST	3.6242	2.551	2.5307	2.5307	2.5982
	SSE	0.0023	0.005	0.0015	0.0015	0.0269
25	SAE	6.0899	6.3769	6.0899	6.0899	6.1486
	OS	6.3478	2.1144	6.3478	6.3478	12.8515
	ST	2.62	2.0619	2.62	2.62	3.5614
	SSE	0.0003	0.0117	0.0003	0.0003	0.0092

The trend that can be clearly seen from Table-1 is that as the number of iteration increases, the fitness for the first priority (SAE) become better (decreases). The same pattern can be seen when number of agents increases. Apart from the analysis of the average of the results, the minimum of the results also an important point to determine the performance of the code. From the minimum result, as shown in Table-2, the value from the number of iteration = 40 and the number of agent = 15 is the cycle run with the best result which is 5.7151 on the Sum Absolute Error (SAE) value. Figure 3 depicts the result of the best minimum result from the MATLAB program shows in a line chart. According to the graph, the SAE value is at about 7.8 at the starting point and ends at

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about 5.7. The trade-off can be seen for OS, ST & SSE where there are certain iteration SAE decreases but either give a counter-productive effect to OS, ST or SSE.

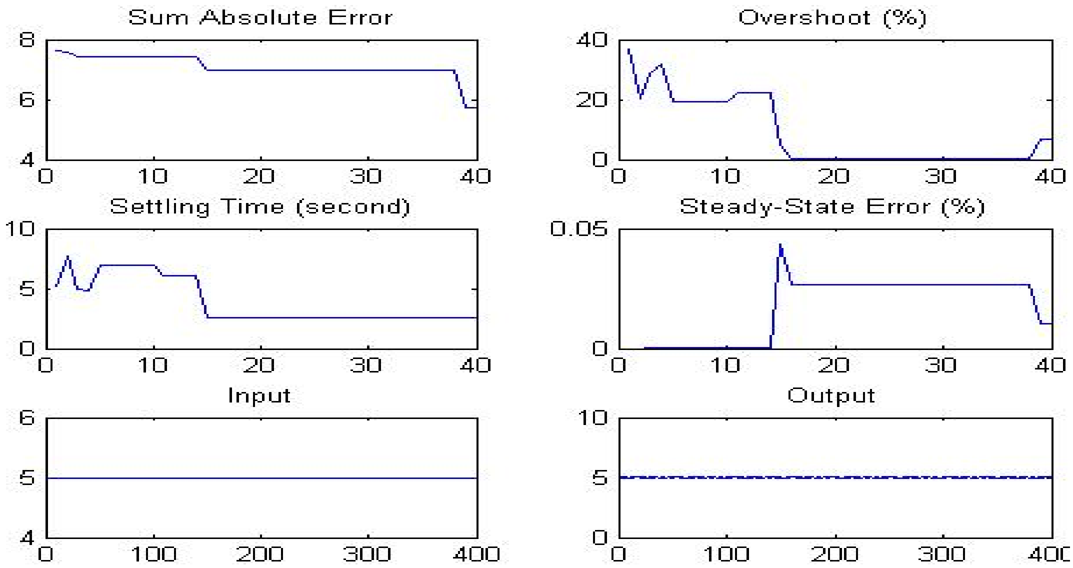

Figure-3. The best minimum result.

CONCLUSIONS

This paper presented the implementation of the BFA in tuning PID Controller parameters for Couple Tank System application. The model of BFA proposed explained concisely. The result obtained were discussed adequately. The result show great correlation between number of iteration and number of agent with better solution found by the proposed approach. Having said that, the proposed approach should be tested with larger number of agent and iteration in order to better gauge the effectiveness of the proposed approach with other algorithms.

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