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Optimal PID Controller Designing for Uncertain Bioreactor Using BFO Algorithm

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Abstract — **Bioreactor plays major role in chemical, biochemical and pharmaceutical industries. The final product quality in a bioreactor depends mainly on the control system employed to supervise and regulate the process. In this article, modified Bacterial Foraging Optimization (BFO) algorithm supported PID controller design is attempted for the bioreactor operating at unstable steady state region. Weighted sum of multiple objective functions is considered as the cost function, which directs the BFO algorithm to find the optimal controller parameters. In this work, an uncertainty of ± 10% is assigned in the process model constraints such as process gain (K), time constant (τ) and delay time (θ). The BFO algorithm based search finds the minimal and maximal values of controller parameters such as K_p, K_i and K_d. The competence of the proposed method has been confirmed through a simulation work. The results show that, the proposed method provides smooth performance in effective reference tracking with minimal error values.**

***IndexTerms*— Bioreactor, modified BFO, uncertainty, multiple objective function, ISE.**

I. Introduction

Biochemicalreactor plays a vital role in chemical, biochemical and pharmaceutical industries to convert the raw material into marketable products such as beverages, antibiotics, vaccines and industrial solvents [1, 2]. The quality of final product in a bioreactor depends mainly on the control loop employed to control the microbial growth. Apart from this, incidental external and internal disturbances in a reactor may result in reactor failure. Hence, there is a strong economic motivation to develop an optimum control scheme to assist rapid start-up and stabilization of continuous bioreactors subject to redundant disturbances [4].

In the process control literature, a variety of methods have been discussed to employ a robust control scheme for the bioreactor operating at single or multiple steady states [3, 5].PID controllers are still extensively employed in industrial process control systems because of their structural simplicity, reputation, robust behavior, and easy implementation [5,6]. The traditional PID tuning procedure existing for stable and unstable processes are model dependent and require numericalcomputations.

Recently, heuristic algorithm based PID tuningapproach is extensively discussed in the literature because of its simplicity, high computational competence, easy execution and stable convergence [8-10, 19-21]. In this work, modified BFO supported PID controller design is proposed for a bioreactor operating at unstable operating region. The performance of the proposed tuning technique is evaluated with a simulation work.

The remaining part of the paper is ordered as follows: Description of bioreactor is provided in section 2, section 3 presents the summary of Bacterial Foraging Optimization algorithm. PID controller design is discussed in section 4. Section 5 gives the simulated results followed by the conclusion of the present research work in section 6.

II. Process Description

Bioreactoris a reactor system used to execute a number of biological reactions in a liquid medium to form intermediate and final products. Figure.1 depicts the diagram of abioreactor [1, 2].

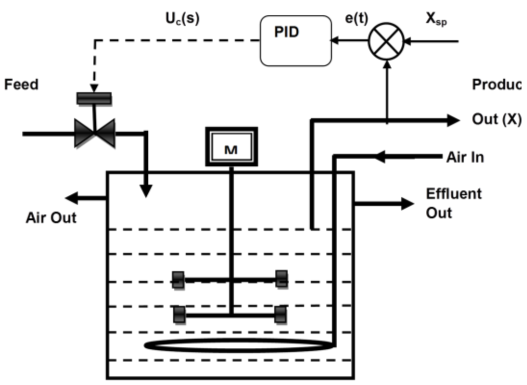

Figure 1 Illustration of a bioreactor

A number of studies are available in the literature for model based control of bioreactor [5,6,18]. In this work, a small scale bioreactor widely analysed by the researchers is considered and the corresponding mathematical equations are represented below [3,5];

Cell balance : $$\frac{dX}{dt} = (\mu - D)X \quad (1)$$

Substrate balance : $$\frac{dS}{dt} = D(S_f - S) - \frac{\mu X}{Y} \quad (2)$$

Product balance : $\frac{dP}{dt} = -D\,P + (\alpha\,\mu + \beta)\,X$ (3)

Monod kinetics : $\mu = \frac{\mu_{max}\,S}{K_m + S}$ (4)

where, 'μ' is specific growth rate, 'X' the biomass concentration, 'S' the substrate concentration and 'α' and 'β' are yield parameters for the product. At steady state, the variables will be; $X = X_s$, $S = S_s$, and $P = P_s$.

Theunstablebioreactormodelisabenchmarkproblemintheunstablesystemstudy. The unstable model is obtained with the following parameters;
μ_{max} = 0.53 hr^{-1}, k_m = 0.12g/lit, k_1=0.4545 lit/g, Y = 0.4. Steady state dilution rate is D_s = 0.3 h^{-1} (the residence time is 3.33 h) and the feed substrate concentration is X_{fs} = 4.0 g/lit. The nonlinear process has the three steady state operating points for a dilution rate of 0.3 h^{-1}. For the unstable operating region the biomass concentration value is X_{1s} = 0.9951 and substrate concentration value is X_{2s} =1.5122. The dilution rate is taken as the manipulated variable to control the cell mass concentration at the unstable steady state.
For the unstable operating region, the following linear model is obtained [3].

$$G_p(s) = \frac{-0.9951s - 0.2985}{s^2 + 0.1302s - 0.0509}\,e^{-\theta\,s} \quad (5)$$

$$= \frac{-5.8644}{5.89s - 1}\,e^{-\theta\,s} \quad (6)$$

Eqn. 5 represents the second order model and Eqn. 6 shows the first order model. The delay time (θ) for both the models is assigned as 0.1.

For uncertainty analysis, the first order model is considered and model perturbation of ± 10% is assigned for the process parameters like, process gain (K), process time constant (τ) and delay time (θ) [23]. The general first order uncertain model is given in Eqn. 7.

$$\overset{\Delta}{G}(s) = \frac{(K \pm \Delta K)}{(\tau \pm \Delta\tau)s - 1}\,e^{-(\theta + \Delta\theta)s} \quad (7)$$

III. Related Previous Work

In the literature, there exists a variety of methodoly to analyze and control biochemical reactor. The detailed modelling procedure of the bioreactor is described in the books [1-3]. Zhao and Skogestad discussed various possible control configuration of the bioreactor system [4]. Pramod and Chidambaram discussed the identification and model based PID controller design for bioreactor operating at unstable steady state [6]. Rajinikanth and Latha proposed heuristic algorithms such as Particle Swarm Optimization (PSO) and BFO to tune the PID and modified structured PID controller for a class of unstable systems [8 -17]. A detailed modeling procedure for bioreactor is presented in the paper byRajinikanth and Latha [18]. Roeva and Slavov discussed heuristic algorithm based PID controller design for an industrial type bioreactor [19 -21]. Slavov and Roeva discussed geneticalgorithm based PID controller design to control glucose concentration in a bioreactor [22].A detailed description of PID and modified structured PID controller design for a class of unstable processes is discussed in the book by Padmasree and Chidambaram [5].

IV. Bacterial Foraging Optimization Algorithm

Bacteria Foraging Optimization (BFO) algorithm is a population supportedmethod, developed by inspiring the foraging manners of E.coli bacteria [7]. Due to its stable and superior convergence, it is widely considered to design PID controller for a class of time delayed unstable processes [10, 11,15,16]. In this paper, enhanced BFO algorithm discussed by Rajinikanth and Latha [13] is considered and the algorithm parameters are assigned as follows:

- Number of E.Coli bacteria = N = 20
- Nnumber of chemotactic steps (N_c) = $\frac{N}{2}$
- Swim length (N_s) = $\frac{N}{3}$
- Number of reproduction steps (N_{re}) ≈ $\frac{N}{3}$
- Number of dispersal events (N_{ed}) ≈ $\frac{N}{4}$
- Number of bacterial reproduction (N_r) = $\frac{N}{2}$
- Probability of the bacterial elimination/dispersal (P_{ed}) = $\left(\frac{N_{ed}}{N + N_r}\right)$
- Number of iterations during the search = N^2
- Swarming parameters can be assigned as follows:

$$d_{att} = W_{atr} = \frac{N_s}{N}; \quad \text{and} \quad h_{rep} = W_{rep} = \frac{N_c}{N}$$

V. PID Controller Design

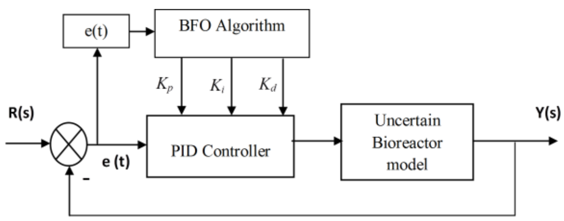

Figure 2 BFO algorithm based PID design

The parallel structure of PID controller is used to control the bioreactor. Mathematical representation of parallel structure of PID controller is presented in Eqn.8.

$$G_{PID}(s) = \left(K_p + \frac{K_i}{s} + \frac{K_d\,s}{T_f\,s + 1}\right) \quad (8)$$

where $\tau_f$if the filter time constant(τ_f = τ_d / N and N=10).

The following performance criterion (Eqn.9) with three parameters, such as *ISE*, $M_p$and t_s are considered in this work.

$$J(K_p, K_i, K_d) = (w_1.\ ISE) + (w_2.\ M_p) + (w_3.\ T_s) \quad (9)$$

where $ISE = \int_0^T e^2(t)\,dt = \int_0^{100} [r(t) - y(t)]^2\,dt$ (10)

$M_p = y(t) - r(t)$ (11)

t_s = settling time ; T = total simulation time.

(w_1, w_2 and w_3 are weighting parameters, to assign priority for cost functions and the value of 'w' varies from 0 to 1)

The performance measure $J(K_p, K_i, K_d)$ monitors the BFO algorithm to get suitable values for PID controller.In this work, the following values are considered:

- Dimension of the search (D) = 3
- The total number of E.Coli bacteria = 20
- The weighting function values are assigned as $w_1 = 1$, $w_2 = 0.5$ and $w_3 = 0.5$
- Search boundary is assigned as -100% and + 100% for K_p, K_i and K_d.

VI. Results and Discussion

The performance of the proposed PID controller design is tested on the first order bioreactor model with parameter uncertainty. Ten trials are performed using the BFO algorithm and the best controller value among 10 trials is chosen as the optimal PID value.

The normal first order transfer function model of the unstable bioreactor is considered and the BFO algorithm based controllerdesign is proposed with the method as shown in Figure2. The multiple cost function basedsearch is converged at 165th iteration with the following controller parameters; K_p =-0.5428, K_i = -0.1153 and K_d = -0.3019. Final convergence of bacteria in the three dimensional search space is shown in Figure 3.

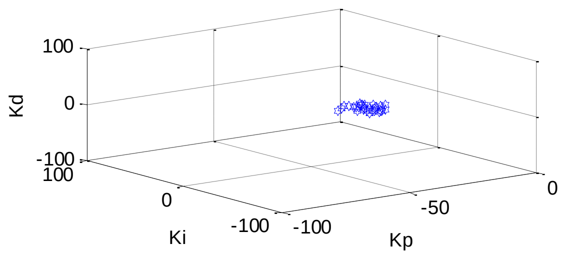

Figure 3 Convergence of E. coli bacteria

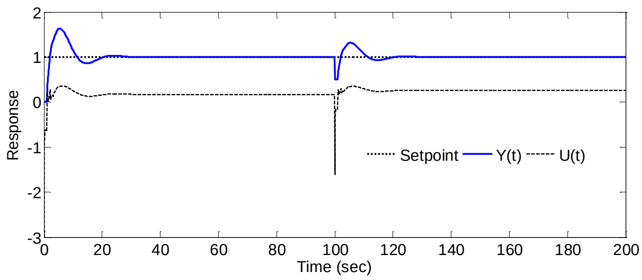

Figure 4Servo and regulatory operations

Figure 4 depicts the servo and regulatory performances of the bioreactor with the above said PID controller parameters. A setpoint of 0.9951 g / lit is applied and a load disturbance of 50% of setpoint is applied at 100 sec. From Figure 4, it is noted that, the PID controller provides a flat reference tracking and disturbance elimination performances with an overshoot of 0.572 g / lit and a settling time of 31.4 sec. The controller output (U(t)) also smooth and it is free from the proportional and derivative kick effect.

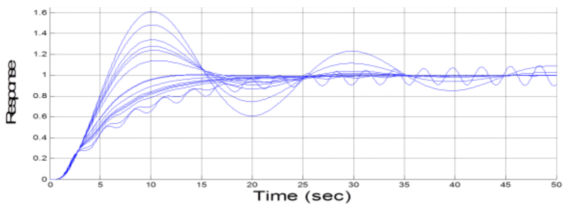

Figure 5Reference tracking performance for the bioreactor model with ± 10% uncertainty

The performance of the above controller is then tested on the uncertain first order model of the bioreactor and the result is depicted in Figure 5. When the uncertainty is lesser than 10%, the controller provides a nearly stable response.

Finally, the robustness of the BFO based PID controller is examinedusing the nonlinear unstable bioreactor model developed with Eqn 1 – 4. A zero mean white noise signal with an amplitude of 0.1 is added in feedback path to test the reference tracking performance of the PID controller.

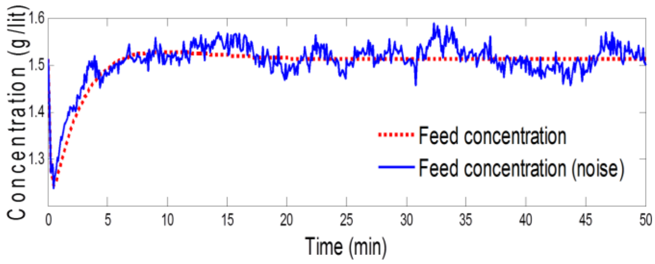

Figure 6Variation of feed concentration

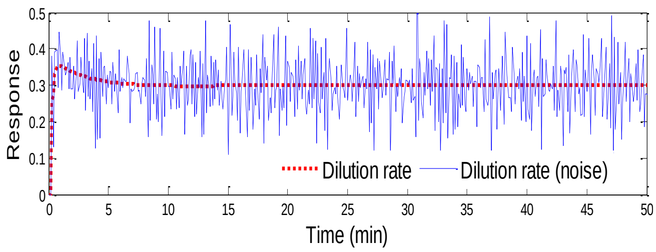

Figure 7Variation of dilution rate

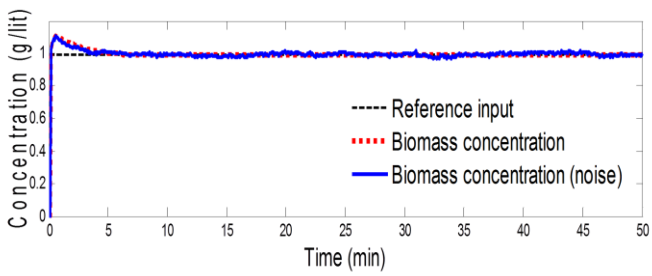

Figure 8 Variation of biomass concentration

Figure 6 and Figure 7 shows the variation of feed concentration and dilution rate respectively. Figure 8 depicts the change in biomass concentration. The rise time, overshoot and the settling time obtained for biomass concentration is excellent. From the above figures, it is noted that, the proposed PID controller provides a smooth response in the presence and absence of measurement noise signal and it works well on the nonlinear bioreactor model.

VII. Conclusions

In this work, modified BFO algorithm basedPID controller design is discussed for unstable bioreactor model with and without model uncertainty. The design of controller is formulated as an optimization problem using weighted sum of multiple objective function as the cost function. This method is a model freemethod, which provides the optimal controller parameters successfully. The result obtained from the simulation study shows that the discussed method works well in the linear and nonlinear model of the bioreactor and supports smooth set point tracking and disturbance rejection operations.

References

[1] Amiya K. Jana, “Chemical Process Modeling and Computer Simulation”, Prentice-Hall of India Pvt Ltd, India, pp. 63 – 78, 2008.

[2] E.M.T. El-Mansi and C.F.A. Bryce, “Fermentation Microbiology and Biotechnology”, *Taylor and Francis, Indian reprint*, pp.49-68, 2003.

[3] B. Wayne Bequette, “Process Control – Modeling, Design and Simulation”, Prentice – Hall of India Pvt Ltd, pp. 631 – 638, 2003.

[4] Ying Zhao and Sigurd Skogestad, “Comparison of Various Control Configurations for Continuous Bioreactors”, Ind. Eng. Chem. Res., Vol.36, pp. 697-705, 1997.

[5] R. Padmasree and M. Chidambaram, “Control of Unstable Systems”, Narosa Publishing House, India, 2006.

[6] S. Pramod and M.Chidambaram, “Closed loop identification of transfer function model for unstable bioreactors for tuning PID controllers”, Bioprocess engineering, Vol. 22, pp. 185-188, 2000.

[7] Kevin M. Passino, “Biomimicry of bacterial foraging for distributed optimization and control”, IEEE Control Systems Magazine, pp.52-67, 2002.

[8] V. Rajinikanth and K. Latha, “Identification and control of unstable biochemical reactor”, International Journal of Chemical Engineering and Applications, Vol. 1, No.1, pp. 106 -111, 2010.

[9] V. Rajinikanth and K. Latha, “Optimization of PID controller parameters for unstable chemical systems using soft computing technique”, International Review of Chemical Engineering (I.RE.CH.E.), Vol. 3, No. 3, pp.350-358, 2011.

[10] V. Rajinikanth and K. Latha, “Bacterial foraging optimization algorithm based PID controller tuning for time delayed unstable system”, The Mediterranean Journal of Measurement and Control, Vol. 7, No. 1 , pp. 197-203, 2011a.

AUTHOR DETAILS

[11] V. Rajinikanth and K. Latha, “I-PD controller tuning for unstable system using bacterial foraging algorithm: a study based on various error criterion”, Applied Computational Intelligence and Soft Computing, vol. 2012, Article ID 329389, 10 pages, 2012. Doi:10.1155/2012/329389.

[12] V. Rajinikanth and K. Latha, “Tuning and retuning of PID controller for unstable systems using evolutionary algorithm”, ISRN Chemical Engineering, vol. 2012, Article ID 693545, 11 pages, 2012. Doi:10.5402/2012/693545.

[13] V. Rajinikanth and K. Latha, “Controller parameter optimization for nonlinear systems using enhanced bacteria foraging algorithm”, Applied Computational Intelligence and Soft Computing, vol. 2012, Article ID 214264, 12 pages, 2012. Doi:10.1155/2012/214264.

[14] V. Rajinikanth and K. Latha, “Internal Model Control – Proportional Integral Derivative controller tuning for first order plus time delayed unstable systems using BFO algorithm”, Scientific Research and Essays, Vol. 7, No. 40, pp. 3406-3420, 2012. DOI: 10.5897/SRE12.282.

[15] V. Rajinikanth and K. Latha, “Setpoint weighted PID controller tuning for unstable system using heuristic algorithm”,
Archives of Control Sciences, Vol. 22, No. 4, pp. 481–505, 2012.

[16] K. Latha and V. Rajinikanth, “2DOF PID controller tuning for unstable systems using bacterial foraging algorithm”, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Vol. 7677 LNCS, pp. 519–527, 2012.

[17] V. Rajinikanth and K. Latha, “Particle swarm approach for identification of unstable processes”, Advances in Intelligent Systems and Computing, Vol. 199 AISC, pp. 505–513, 2013.

[18] V. Rajinikanth and K. Latha, “Modeling, Analysis, and Intelligent Controller Tuning for a Bioreactor: A Simulation Study,” ISRN Chemical Engineering, vol. 2012, Article ID 413657, 15 pages, 2012. doi:10.5402/2012/413657

[19] Olympia Roeva and Tsonyo Slavov, “Firefly algorithm tuning of PID controller for glucose concentration control during E. coli fed-batch cultivation process”, In proceedings of Federated Conference 0n Computer Science and Information Systems (FedCSIS), pp. 455 – 462, 2012.

[20] Olympia Roeva and Tsonyo Slavov, “A New Hybrid GA-FA Tuning of PID Controller for Glucose Concentration Control”, Recent Advances in Computational OptimizationStudies in Computational Intelligence Vol. 470, pp 155-168, 2013.

[21] O. Roeva and T. Slavov, “Fed-Batch Cultivation Control Based on Genetic Algorithm PID Controller Tuning”, In proceedings of NMA 2010, LNCS, vol. 6046, pp. 289–296, 2011.

[22] T. Slavov and O. Roeva, “Genetic Algorithm Tuning of PID Controller in Smith Predictor for Glucose Concentration Control”, International Journal of Bioautomation, Vol. 15, No. 2, pp.101–114, 2011.

[23] T. Babu and N. Pappa, “Uncertainty quantification and sensitivity analysis for a nonlinear bioreactor”, In proceedings of Advances in Computing, Communication, and Control, Communications in Computer and Information Science , CCIS 361, Vol. 361, pp 647-658, 2013.

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