Abstracts of selected publications of Assoc. Prof. Olympia Roeva for participation in the concourse for the academic position "Professor"

I. Publications under Indicator *B4*

1. **Roeva O.,** M. Angelova, D. Zoteva, T. Pencheva, Water Cycle Algorithm for Modelling of Fermentation Processes, Processes, 2020, Vol. 8(8), 920; https://doi.org/10.3390/pr8080920.

The water cycle algorithm (WCA), which is a metaheuristic method inspired by the movements of rivers and streams towards the sea in nature, has been adapted and applied here for the first time for solving such a challenging problem as the parameter identification of fermentation process (FP) models. Bacteria and yeast are chosen as representatives of FP models that are subjected to parameter identification due to their impact in different industrial fields. In addition, WCA is considered in comparison with the genetic algorithm (GA), which is another population-based technique that has been proved to be a promising alternative of conventional optimisation methods. The obtained results have been thoroughly analysed in order to outline the advantages and disadvantages of each algorithm when solving such a complicated real-world task. A discussion and a comparative analysis of both metaheuristic algorithms reveal the impact of WCA on model identification problems and show that the newly applied WCA outperforms GA with regard to the model accuracy.

2. **Roeva O.,** D. Zoteva, O. Castillo, Joint set-up of parameters in genetic algorithms and the artificial bee colony algorithm: an approach for cultivation process modelling, Soft Computing, 2020, https://doi.org/10.1007/s00500-020-05272-1.

One of the most commonly used bacteria for producing medical substances in the pharmaceutical industry is *E. coli.* Creating an effective model for fed-batch cultivation process is therefore very important. The processes in a bioreactor can be described by a system of parametric non-linear differential equations. The problem is to find optimal parameters according to the input data. The model parameter identification is a difficult optimization problem which cannot be solved by applying traditional numerical methods. A more appropriate approach is to apply meta-heuristic method(s). A genetic algorithm for model parameter identification of non-linear fed-batch cultivation process, based on real experimental data, is applied in this study. The influence of crossover and mutation rates on the algorithm performance are investigated. The aim is to study the relations between crossover and mutation, and to find the best values of these parameters for the problem in question. Moreover, the results of this study can help develop better understanding of the relation between crossover and mutation in general (as fundamental aspects of genetic algorithms).

3. Fidanova S., **O. Roeva**, Metaheuristic Techniques for Optimization of an *E. coli* Cultivation Model, Biotechnology and Biotechnological Equipment, Vol. 27(3), 2013, 3870-3876.

In this paper two metaheuristics: Ant Colony Optimization (ACO) and Genetic Algorithms (GA), were compared for parameter identification of an *E. coli* fed-batch cultivation process model. A system of ordinary differential equations was used to model the biomass growth and substrate

utilization. Parameter optimization was performed using a real experimental data set from an *E. coli* MC4110 fed-batch cultivation process. The GA and ACO adjustments were done based on several pre-tests on the optimization problem considered here. Two techniques were compared based on the obtained "best", "worst" and "average" values for estimates and the objective function J. The results showed that the "best" value of the objective function J is achieved by ACO. At the same time, GA achieved better results for "worst" and "average" values. Analyzing the results, it could be concluded that both algorithms: ACO and GA, perform satisfactorily for the problem of parameter optimization of an *E. coli* fed-batch cultivation process model.

4. **Roeva O.,** S. Fidanova, Hybrid Bat Algorithm for Parameter Identification of an *E. coli* Cultivation Process Model, Biotechnology and Biotechnological Equipment, Vol. 27(6), 2013, 4323-4326.

In this paper, a hybrid scheme using Bat Algorithm (BA) and Sequential Quadratic Programming (SQP) method is introduced. In the hybrid BA–SQP, the role of BA is to generate feasible solutions to a problem. The role of SQP is to exploit the information gathered by BA. This process obtains a solution which is at least as good as – but usually better than – the best solution devised by BA. To demonstrate the usefulness of the presented approach, the hybrid scheme was applied to parameter identification of an *E. coli* MC4110 fed-batch cultivation process model. A comparison with both the conventional BA and SQP method is presented. The results showed that the hybrid BA–SQP has the advantages of both BA's global search ability and SQP's local search ability, thus enhancing the overall search ability and computational efficiency. For comparison, the results obtained by applying Ant colony optimization algorithm in conditions similar to those of BA are further shown.

5. **Roeva O.,** V. Atanassova, Cuckoo Search Algorithm for Model Parameter Identification, Int J Bioautomation, Vol. 20(4), 2016, 483-492.

In this paper, the metaheuristics algorithm Cuckoo Search (CS), is adapted and applied for a model parameter identification of an *E. coli* fed-batch cultivation process. The dynamics of bacteria growth and substrate (glucose) utilization is described by a system of ordinary nonlinear differential equations. Using real experimental data set from an *E. coli* MC4110 fed-batch cultivation process a parameter optimization is performed. The simulation results indicate that the applied algorithm is effective and efficient. As a result, a model with high degree of accuracy is obtained applying the CS. The simulation results and comparison with genetic algorithm and ant colony optimization algorithm confirm the effectiveness of the applied CS algorithm in solving a cultivation model parameter identification problem.

6. **Roeva O.,** Optimization of *E. coli* Cultivation Model Parameters Using Firefly Algorithm, Int. J. Bioautomation, Vol. 16(1), 2012, 23-32.

In this paper, a novel meta-heuristics algorithm, namely the Firefly Algorithm (FA), is adapted and applied for a model parameter identification of an *E. coli* fed-batch cultivation process. A system of ordinary nonlinear differential equations is used to model the biomass growth and substrate utilization. Parameter optimization is performed using real experimental data set from an *E. coli* MC4110 fed-batch cultivation process. The FA adjustments are done based on several pre-tests according to the optimization problem considered here. The simulation results indicate that the

applied algorithm is effective and efficient. As a result, a model with high degree of accuracy is obtained applying the FA.

7. **Roeva O.,** S. Fidanova, M. Paprzycki, Population Size Influence on the Genetic and Ant Algorithms Performance in Case of Cultivation Process Modeling, Recent Advances in Computational Optimization, Studies in Computational Intelligence, Vol. 580, 2015, 107-120.

In this paper, an investigation of the influence of the population size on the Genetic Algorithm (GA) and Ant Colony Optimization (ACO) performance for a model parameter identification problem, is considered. The mathematical model of an *E. coli* fed-batch cultivation process is studied. The three model parameters – maximum specific growth rate (μ_{max}), saturation constant (k_S) and yield coefficient ($Y_{S/X}$) are estimated using different population sizes. Population sizes between 5 and 200 chromosomes and 5 and 100 ants in the population are tested with constant number of generations. In order to obtain meaningful information about the influence of the population size a considerable number of independent runs of the GA are performed. The observed results show that the optimal population size is 100 chromosomes for GA and 70 ants for ACO for 200 generations. In this case accurate model parameters values are obtained in reasonable computational time. Further increase of the population size, above 100 chromosomes for GA and 70 ants for ACO, does not improve the solution accuracy. Moreover, the computational time is increased significantly.

8. **Roeva O.,** A Hybrid Genetic Algorithm for Parameter Identification of Bioprocess Models, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Springer, Germany, Vol. 7116, 2012, 247-255.

In this paper a hybrid scheme using GA and SQP method is introduced. In the hybrid GA-SQP the role of the GA is to explore the search place in order to either isolate the most promising region of the search space. The role of the SQP is to exploit the information gathered by the GA. To demonstrate the usefulness of the presented approach, two cases for parameter identification of different complexity are considered. The hybrid scheme is applied for modelling of *E. coli* MC4110 fed-batch cultivation process. The results show that the GA-SQP takes the advantages of both GA's global search ability and SQP's local search ability, hence enhances the overall search ability and computational efficiency.

9. **Roeva O.,** Genetic Algorithm and Firefly Algorithm Hybrid Schemes for Cultivation Processes Modelling, In: Transactions on Computational Collective Intelligence XVII, R. Kowalczyk, A. Fred, F. Joaquim (Eds.), series Lecture Notes in Computer Science, Springer, Vol. 8790, 2014, 196-211.

In this paper two hybrid schemes using Firefly Algorithm (FA) and Genetic Algorithm (GA) are introduced. The novel hybrid meta-heuristics algorithms are realized and applied to parameter identification problem of a non-linear mathematical model of the *E. coli* cultivation process. This is a hard combinatorial optimization problem for which exact algorithms or traditional numerical methods does not work efficiently. A system of four ordinary differential equations is proposed to model the growth of the bacteria, substrate utilization and acetate formation. Parameter optimization is performed using a real experimental data set from an *E. coli* MC4110 fed-batch cultivation process. In the considered non-linear mathematical model five parameters are

estimated, namely maximum specific growth rate, two saturation constants and two yield coefficients. Based on the numerical and simulation result, it is shown that the model obtained by the proposed hybrid algorithms is highly competitive with standard FA and GA. The hybrid algorithms obtain similar objective function values compared to pure GA and FA, but using four times less population size and seven times less computation time. Thus, the hybrids have two advantages – they take much less running time and require much less memory compared to standard GA and FA.

10. **Roeva O.,** S. Fidanova, V. Atanassova, Hybrid ACO-GA for Parameter Identification of an *E. coli* Cultivation Process Model, Lecture Notes in Computer Science, Vol. 8353, 2014, 313-320.

The present work offers a novel approach to parameter identification of an *E. coli* cultivation process model, using a hybrid of two metaheuristics, namely Ant Colony Optimization (ACO) and Genetic Algorithms (GAs). Our basic idea is to generate initial solutions by the ACO method, and then serve these solutions to the GA as its initial population of individuals. Thus, the GA will start with a population, which is not randomly generated, as in the general case, but one rather closer to an optimal solution. The motivation behind this hybridization is to combine the benefits of both approaches, aimed at achieving commensurate calculations precision with less computation resources, in terms of time and memory. The proposed method is approbated with the estimation of the parameters of a real *E. coli* fed-batch cultivation process model. The presented results are affirmative of our goal to yield better performance of the hybrid algorithm: almost twice less computational time and approximately five times smaller populations needed, compared to both ACO and GAs, as taken separately.

II. Publications under Indicator *Г7* and *8*

11. **Roeva O.,** S. Fidanova, Comparison of Different Metaheuristic Algorithms based on Inter-Criteria Analysis, Journal of Computational and Applied Mathematics, Vol. 340, 2018, 615-628.

In this paper InterCriteria analysis (ICrA), based on the apparatus of the Index Matrices and the Intuitionistic Fuzzy Sets, is performed for a model parameters identification using different pure and hybrid metaheuristic techniques. As a case study a non-linear *E. coli* MC4110 fed-batch cultivation process model is considered. Series of cultivation model identification procedures using metaheuristics as genetic algorithms (GA), ant colony optimization (ACO), firefly algorithm (FA) and simulated annealing (SA) are done. The results are compared with the once obtained by applied hybrid algorithms ACO-GA, ACO-FA and GA-ACO. Further, the ICrA is used to explore the existing relations and dependencies of defined cultivation model parameters, namely μ_{max}, k_S and yield coefficient $Y_{S/X}$, and considered metaheuristic algorithms outcomes, e.g. computation time T and objective function value J. Applying ICrA on the obtained average results of model parameters estimates, T and J, some relations between the defined criteria are established. The presented results show some dependences relating to the physical meaning of the considered model parameters and to stochastic nature of the applied in this paper metaheuristic techniques.

12. Velikova V., C. Arena, L. G. Izzo, Ts. Tsonev, D. Koleva, M. Tattini, **O. Roeva**, A. De Maio, F. Loreto, Functional and Structural Leaf Plasticity Determine Photosynthetic Performances during Drought Stress and Recovery in Two Platanus orientalis Populations from Contrasting Habitats,

International Journal of Molecular Science, Vol. 21(11), 2020, 3912; https://doi.org/10.3390/ijms21113912.

In the context of climatic change, more severe and long-lasting droughts will modify the fitness of plants, with potentially worse consequences on the relict trees. We have investigated the leaf phenotypic (anatomical, physiological and biochemical) plasticity in well-watered, drought-stressed and re-watered plants of two populations of *Platanus orientalis*, an endangered species in the west of the Mediterranean area. The two populations originated in contrasting climate (drier and warmer, Italy (IT) population; more humid and colder, Bulgaria (BG) population). The IT control plants had thicker leaves, enabling them to maintain higher leaf water content in the dry environment, and more spongy parenchyma, which could improve water conductivity of these plants and may result in easier CO_2 diffusion than in BG plants. Control BG plants were also characterized by higher photorespiration and leaf antioxidants compared to IT plants. BG plants responded to drought with greater leaf thickness shrinkage. Drought also caused substantial reduction in photosynthetic parameters of both IT and BG plants. After re-watering, photosynthesis did not fully recover in either of the two populations. However, IT leaves became thicker, while photorespiration in BG plants further increased, perhaps indicating sustained activation of defensive mechanisms. Overall, our hypothesis, that plants with a fragmented habitat (i.e., the IT population) lose phenotypic plasticity but acquire traits allowing better resistance to the climate where they became adapted, remains confirmed.

13. Lyubenova V., M. Ignatova, **O. Roeva**, S. Junne, P. Neubauer, Adaptive Monitoring of Biotechnological Processes Kinetics, Processes, 2020, 8(10), 1307. https://doi.org/10.3390/pr8101307.

In this paper an approach for monitoring of biotechnological processes' kinetics is proposed. The kinetics of each process state variable is presented as function of two time-varying unknown parameters. For their estimation a general software sensor is derived with inputs on-line measurements accessible in practice. The stability analysis with different number of inputs shows that stability can be guaranteed for fourth and fifth order software sensors only. As a case study, monitoring of the kinetics of processes carried out in stirred tank reactors is investigated. A new tuning procedure is derived that results in choice of only one design parameter. The effectiveness of the proposed procedure is demonstrated with experimental data from *Bacillus subtilis* fed-batch cultivations.

14. **Roeva O.**, D. Zoteva, V. Atanassova, K. Atanassov, O. Castillo, Cuckoo search and firefly algorithms in terms of generalized net theory, Soft Computing, Vol. 24, 2020, 4877-4898, https://doi.org/10.1007/s00500-019-04241-7.

In the presented paper, the functioning and the results of the work of two metaheuristic algorithms, namely Cuckoo Search algorithm (CS) and Firefly Algorithm (FA), are described using the apparatus of generalized nets (GNs), which is an appropriate and efficient tool for describing the essence of various optimization methods. The two developed GN-models mimic the optimization processes based on the nature of cuckoos and fireflies. The proposed GN-models execute the two considered metaheuristic algorithms conducting basic steps and performing optimal search. Building upon these two GN-models, a *universal* GN-model is constructed that can be used for describing and simulating both the CS and the FA by setting different characteristic

functions of the GN-tokens. Moreover, the *universal* GN-model itself can be transformed to each of the herewith presented GN-models by applying appropriate hierarchical operators. In order to validate the proposed *universal* GN-model, numerical experiments are performed for the operating of the *universal* GN-model (CS and FA) on benchmark mathematical functions. The obtained results are compared with the results of the GN-model of CS, GN-model of FA, as well as the results of the standard CS and FA.

15. Ilkova T., **O. Roeva**, M. Petrov, Multiple Objective Optimisation of Batch Cultivation of Saccharomyces cerevisiae in Mixing System, Biotechnology and Biotechnological Equipment, Vol. 27(5), 2013, 4162-4166.

Multiple objective optimisation is a natural extension of the traditional optimisation of a single objective function. On one hand, if the multiple objective functions are commensurate, minimizing single objective function, it is possible to minimize all criteria and the problem can be solved using traditional optimisation techniques. On the other hand, if the objective functions are incommensurate or competing, then the minimization of one objective function requires a compromise in another objective function. The competition between multiple objective functions is a key distinction between the multiple objective optimisation and traditional single objective optimisation. In our investigations we discussed the problems of multiple objective optimisation of a batch cultivation of the *Saccharomyces cerevisiae* in different mixing systems (impulse and vibromixing) for searching the maximal rotation speed, initial conditions, and amplitude is developed. The multiple objective optimisation problems are transformed to a single objective function with weight coefficients. The applied multiple objective optimisation of the process has shown vast increase of their productivity, respectively decrease in the residual substrate concentration. This result leads to a higher economical effectiveness for each of them at a smaller outlay.

16. **Roeva O.,** T. Pencheva, Functional state modelling approach validation for yeast and bacteria cultivations, Biotechnology and Biotechnological Equipment, Vol. 18(3), 2014, 207-214.

In this paper, the functional state modelling approach is validated for modelling of the cultivation of two different microorganisms: yeast (*Saccharomyces cerevisiae*) and bacteria (*Escherichia coli*). Based on the available experimental data for these fed-batch cultivation processes, three different functional states are distinguished, namely primary product synthesis state, mixed oxidative state and secondary product synthesis state. Parameter identification procedures for different local models are performed using genetic algorithms. The simulation results show high degree of adequacy of the models describing these functional states for both *S. cerevisiae* and *E. coli* cultivations. Thus, the local models are validated for the cultivation of both microorganisms. This fact is a strong structure model verification of the functional state modelling theory not only for a set of yeast cultivations, but also for bacteria cultivation. As such, the obtained results demonstrate the efficiency and efficacy of the functional state modelling approach.

17. Ilkova T., M. Petrov, **O. Roeva**, Optimization of a whey bioprocess using neuro-dynamic programming strategy, Biotechnology and Biotechnological Equipment, Vol. 26(5), 2012, 3249-3253.

A method for finding the optimal feeding profile for whey fermentation by strain *Kluyveromyces lactic* MC 5 in a fed-batch bioreactor was developed. The optimal profile maximizes the process effectiveness and minimizes the bioprocess duration. The method is based on Neuro-dynamic Programming (NDP), wherein the optimal control decision is parameterized in the form of a cost-to-go function. The suggested method employs simulations from a heuristic feeding strategy as an initial point to generate the cost-to-go to experimental data. A neural network is applied to obtain cost-to-go as a function of system state. Iterations of the Bellman equation are included to improve the cost function. Thus, the obtained approach guarantees optimal control of the bioreactor when disturbances are present. The developed approach was compared with other methods – the Pontryagin's Maximum Principle and Fuzzy Sets Theory. The NDP method provided better results than the other methods.

18. Slavov Ts., **O. Roeva**, Multiple Non-Linear Model Adaptive Control of Cultivation Process: Hardware-in-the-Loop Simulation of Control System, Comptes rendus de l'Académie bulgare des Sciences, Vol. 67(4), 2014, 577-584.

The results from hardware-in-the-loop (HIL) simulation of multiple model adaptive control (MMAC) algorithm for feedback feedforward control of a non-stationary cultivation process implemented in programmable logic controller are presented. The developed software platform allows to implement easily different cultivation process parameters variations, different local controllers and local models and makes possible the investigation of the closed-loop system behavior in the presence of different non-stationarities. The presented results show that the controller adapts to the parameter variations, accurately controls the feed rate and keeps the glucose concentration at the desired set point in the presence of significant parametric disturbances and measurement noise. The results obtained by HIL simulation are close to the results obtained by Simulink® simulation.

19. Slavov Ts., **O. Roeva**, Multiple Non-linear Model Adaptive Control of Cultivation Process: Control Algorithm Design, Comptes rendus de l'Académie bulgare des Sciences, Vol. 67(3), 2014, 411-418.

The aim of this paper is to present the developed multiple model adaptive control algorithm for feedback feedforward control of a non-stationary *E. coli* fed-batch cultivation process. Compared to the existing MMAC algorithms based on the input-output models, the present one uses the bank of non-linear plant models and the bank of feedforward feedback controllers. Moreover, the MMAC algorithm uses the new technique for on-line computation of weighting coefficients.

20. Georgieva V., N. Angelova, **O. Roeva**, T. Pencheva, Simulation of Parallel Processes in Wastewater Treatment Plant Using Generalized Net Integrated Development Environment, Comptes rendus de l'Academie bulgare des Sciences, Vol. 69(11), 2016, 1493-1502.

This paper presents the first generalized net (GN) model of a typical wastewater treatment plant (WTP) developed in Generalized Nets Integrated Development Environment (GN IDE). Based on real experimental data the developed GN model is further simulated in GN IDE. The implemented here simulation of WTP complex parallel processes allows real time monitoring of various significant parameters. Based on the tracking of main process parameters, such as water quantity, pH, COD, petrol, different mechanical admixtures, PO_4P, NH_4N, etc., some suggestions concerning

the optimal running of the WTP process could be proposed. Presented results show the developed GN model efficiency, the benefits of performed parallel simulation of real experimental data and GN IDE effectiveness in such challenging tasks.

21. **Roeva O.**, Ts. Slavov, PID Controller Tuning based on Metaheuristic Algorithms for Bioprocess Control, Biotechnology and Biotechnological Equipment, Vol. 26(5), 2012, 3267-3277.

This paper presents an optimal tuning of a universal digital PID controller using metaheuristics as Genetic Algorithms (GA), Simulated Annealing (SA) and Tabu Search (TS). The controllers were used to control the feed rate and to maintain the glucose concentration at the desired set point for an *E. coli* MC4110 fed-batch cultivation process. The mathematical model of the cultivation process was represented by the dynamic mass balance equations for biomass and substrate. In the control algorithm the design measurement and process noise as well as the time delay of the glucose measurement system were taken into account. To achieve good closed-loop system performance metaheuristics based controller tuning was done. By tuning the constants (K_p, T_i, T_d, b, c and N) in the PID controller algorithm, the controller can provide control action designed for the specific process requirements. To evaluate the significance of the tuning procedure and controller performance different criteria were used. Objective function values and CPU time were used as criteria to compare the performance of the three metaheuristic algorithms – GA, SA and TS. A series of procedures for PID controller tuning were performed using competing techniques and criteria. As a result, the set of optimal PID controller settings was obtained. For a short time, the controller set the control variable and maintained it at the desired set point during the *E. coli* MC4110 fed-batch cultivation process. The simulation results indicate that the proposed metaheuristic algorithms are effective and efficient, and demonstrate that the applied techniques exhibit a significant performance improvement over classical optimization methods.

22. **Roeva O.**, P. Vassilev, S. Fidanova, M. Paprzycki, InterCriteria Analysis of Genetic Algorithms Performance, Studies of Computational Intelligence, Vol. 655, 2016, 235-260.

In this paper we apply InterCriteria Analysis (ICrA) approach based on the apparatus of Index Matrices and Intuitionistic Fuzzy Sets. The main idea is to use ICrA to establish the existing relations and dependencies of defined parameters in a non-linear model of an *E. coli* fed-batch cultivation process. We perform a series of model identification procedures applying Genetic Algorithms (GAs). We proposed a schema of ICrA of ICrA results to examine the obtained model identification results. The discussion about existing relations and dependencies is performed according to criteria defined in terms of ICrA. We consider as ICrA criteria model parameters and GAs outcomes on the one hand, and 14 differently tuned GAs on the other. Based on the results, we observe the mutual relations between model parameters and GAs outcomes, such as computation time and objective function value. Moreover, some conclusions about the preferred tuned GAs for the considered model parameter identification in terms of achieved accuracy for given computation time are presented.

23. **Roeva O.**, S. Fidanova, M. Paprzycki, InterCriteria Analysis of ACO and GA Hybrid Algorithms, Studies in Computational Intelligence, Vol. 610, 2016, 107-126.

In this paper, the recently proposed approach for multicriteria decision making – InterCriteria Analysis (ICA) – is presented. The approach is based on the apparatus of the index matrices and

the intuitionistic fuzzy sets. The idea of Inter-Criteria Analysis is applied to establish the relations and dependencies of considered parameters based on different criteria referred to various metaheuristic algorithms. A hybrid scheme using Genetic Algorithm (GA) and Ant Colony Optimization (ACO) is used for parameter identification of *E. coli* MC4110 fed-batch cultivation process model. In the hybrid GA-ACO, the GA is used to find feasible solutions to the considered optimization problem. Further ACO exploits the information gathered by GA. This process obtains a solution, which is at least as good as—but usually better than—the best solution devised by GA. Moreover, a comparison with both the conventional GA and ACO identification results is presented. Based on ICA the obtained results are examined and conclusions about existing relations and dependencies between model parameters of the *E. coli* process and algorithms parameters and outcomes, such as number of individuals, number of generations, value of the objective function and computational time, are discussed.

24. **Roeva O.,** Ts. Slavov, Fed-batch Cultivation Control based on Genetic Algorithm PID Controller Tuning, Lecture Notes in Computer Science, Vol. 6046, 2011, 289-296.

In this paper a universal discrete PID controller for the control of *E. coli* fed-batch cultivation processes is designed. The controller is used to control feed rate and to maintain glucose concentration at the desired set point. Tuning the PID controller, to achieve good closed-loop system performance, using genetic algorithms is proposed. As a result, the optimal PID controller settings are obtained. For a short time, the controller sets the control variable and maintains it at the desired set point during the process. Application of the designed controller provides maintaining of the accuracy and efficiency of the system performance.

25. **Roeva O.,** V. Atanassova, Universal Generalized Net Model for Description of Metaheuristic Algorithms: Verification with the Bat Algorithm, Advances in Intelligent Systems and Computing, Vol. 643, 2018, 244-255.

In the present paper, the apparatus of generalized nets is used to describe the metaheuristic technique Bat algorithm. Generalized nets are considered an effective and appropriate tool for description of the logics of different optimization techniques. As a result, the developed generalized net model executes the Bat algorithm procedures, conducting basic steps and performing optimal search. The paper elaborates on the already proposed Universal generalized net model for description of the population-based metaheuristic algorithms, which was used so far to model the Cuckoo search, Firefly algorithm and Artificial bee colony optimization, and is used here for modelling of Bat algorithm. It is shown that the Bat algorithm can be described in terms of Universal generalized net model by only varying the characteristic functions of the tokens. Thus, verification of the Universal generalized net model is performed.

26. **Roeva O.,** Ts. Slavov, A New Hybrid GA-FA Tuning of PID Controller for Glucose Concentration Control, In Recent Advances in Computational Optimization (Fidanova S., Ed.), Studies in Computational Intelligence, Vol. 470, 2013, 155-168.

In this paper a hybrid scheme using Firefly Algorithm (FA) - Genetic Algorithm (GA) is introduced. The novel hybrid meta-heuristics algorithm is realized and applied to PID controller parameter tuning in Smith Predictor for a nonlinear control system. The controller is used to control feed rate and to maintain glucose concentration at the desired set point for an *E. coli* MC4110 fed-batch

cultivation process. The hybrid FA-GA adjustments are done based on several pre-tests. Simulation results indicate that the applied hybrid algorithm is effective. Good closed-loop system performance is achieved on the basis of the considered PID controllers tuning procedures. Moreover, the observed results are compared to the ones obtained by applying the pure FA and pure GA. The comparison shows that the proposed hybrid algorithm is highly competitive with standard FA and GA for considered here optimization problem.

27. Slavov Ts., **O. Roeva**, Application of Genetic Algorithm to Tuning a PID Controller for Glucose Concentration Control, WSEAS Transaction on Systems, Vol. 11(7), 2012, 223-233.

The paper presents a feedforward feedback (PID) controller designed for control of glucose concentration during the *E. coli* fed-batch cultivation process. The controller is used to control the feed rate and to maintain glucose concentration at a desired set point. Taking into account the measurement system particularities, the modified process model is proposed. An equation for correction of the measured glucose based on Kalman filter estimates of biomass concentration and bacteria growth rate is suggested. To achieve good closed-loop system performance genetic algorithm tuning of the PID controller is used. As a result, the optimal PID controller settings are obtained. For a short time, the controller sets the control variable and maintains it at the desired set point during the process. Based on the proposed model correction, the estimations of the process parameters are brought closer to the real values. Tuning of the controller on the basis of a genetic algorithm leads to higher level of accuracy and efficiency of the system performance.

28. **Roeva O.,** Ts. Slavov, S. Fidanova, Chapter 7. Population-based vs. Single Point Search Meta-heuristics for a PID Controller Tuning, In: Handbook of Research on Novel Soft Computing Intelligent Algorithms: Theory and Practical Applications, P. Vasant (Ed.), (2 Volumes), IGI Global, 2014. pp. 200-230. Web. 8 May. 2013. doi: https://doi.org/10.4018/978-1-4666-4450-2, ISBN13: 9781466644502, ISBN10: 1466644508, EISBN13: 9781466644519.

This chapter presents a comparison of population-based and single point search meta-heuristic methods applied to an optimal tuning of a universal digital proportional-integral-derivative (PID) controller. In the group of population-based meta-heuristics Genetic Algorithms (GA), Firefly Algorithm (FA) and Ant Colony Optimization (ACO) are considered. In the group of single point search meta-heuristic methods Simulated Annealing (SA), Threshold Accepting (TA) and Tabu Search (TS) are considered. The PID controllers were used to control the feed rate and to maintain the glucose concentration at the desired set point for an *E. coli* MC4110 fed-batch cultivation process. The mathematical model of the cultivation process was represented by dynamic non-linear mass balance equations for biomass and substrate. In the control algorithm the design measurement and process noise as well as the time delay of the glucose measurement system were taken into account. To achieve good closed-loop system performance meta-heuristics based controller tuning was done. By tuning the constants (K_p, T_i, T_d, b, c and N) in the PID controller algorithm, the controller can provide control action designed for the specific process requirements. As a result, the set of optimal PID controller settings was obtained. For a short time, the controllers set the control variable and maintained it at the desired set point during the *E. coli* MC4110 fed-batch cultivation process. Average, best and worst objective function values and PID controller's parameters were used as criteria to compare the performance of the considered meta-heuristic algorithms. The simulation results indicate that the population-based meta-heuristics performs better than the single point search methods considered here. Moreover, GA

and ACO show better performance than FA. Regarding the applied single point search methods, it should be noted that although TS is much simpler than the population-based and SA and TA methods, obtained TS results are comparable to those of FA. The results show that SA and TA algorithms failed to solve the considered here PID controller tuning problem, compared to the other four meta-heuristics.

29. **Roeva O.** Application of Artificial Bee Colony Algorithm for Model Parameter Identification. In: Zelinka I., Vasant P., Duy V., Dao T. (Eds.) Innovative Computing, Optimization and Its Applications. Studies in Computational Intelligence, Vol. 741. Springer, Cham, 285-303, 2018, doi: https://doi.org/10.1007/978-3-319-66984-7_17, ISBN: 978-3-319-66983-0.

In this chapter, the Artificial bee colony (ABC) algorithm, based on the foraging behaviour of honey bees, is introduced for a numerical optimization problem. The ABC algorithm is one of the efficient population-based biological-inspired algorithms. To demonstrate the usefulness of the presented approach, the ABC algorithm is applied to parameter identification of an *E. coli* MC4110 fed-batch cultivation process model. The mathematical model of *E. coli* MC4110 cultivation process is considered as a system of three ordinary differential equations, describing the two main process variables, namely biomass and substrate dynamics, as well as the volume variation. This case study has not been solved previously in the literature by application of ABC algorithm. To obtain a better performance of the ABC algorithm, i.e. high accuracy of the solution within reasonable time, the influence of the algorithm parameters has been investigated. Eight ABC algorithms are applied to parameter identification of the *E. coli* cultivation process model. The results are compared, based on obtained estimates of model parameters, objective function value, computation time and some statistical measures. As a result, two algorithms are chosen – ABC1 and ABC8, respectively, with 60×500 number and 20×400 (population×maximum cycle number), such as algorithms with the best performance. Further, the best ABC algorithms are compared with four population-based biological-inspired algorithms, namely Genetic algorithm, Ant colony optimization, Firefly algorithm and Cuckoo search algorithm. The results from literature of metaheuristics applied for the considered here parameter identification problem are used. The results clearly show that the ABC algorithm outperforms the biological-inspired algorithms under consideration, taking into account the overall search ability and computational efficiency.