

## Chapter 7

# Population–Based vs. Single Point Search Meta–Heuristics for a PID Controller Tuning

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### ABSTRACT

*This chapter presents a comparison of population-based (e.g. Genetic Algorithms (GA), Firefly Algorithm (FA), and Ant Colony Optimization (ACO)) and single point search meta-heuristic methods (e.g. Simulated Annealing (SA), Threshold Accepting (TA), and Tabu Search (TS)) applied to an optimal tuning of a universal digital proportional-integral-derivative (PID) controller. The PID controllers control feed rate and maintain glucose concentration at the desired set point for an E. coli MC4110 fed-batch cultivation process. The model of the cultivation process is represented by dynamic non-linear mass balance equations for biomass and substrate. In the control the design measurement, process noise, and time delay of the glucose measurement system were taken into account. To achieve good closed-loop system the constants ( $K_p$ ,  $T_i$ ,  $T_d$ ,  $b$ ,  $c$  and  $N$ ) were tuned in the PID controller algorithm so the controller can provide control action designed for the specific process requirements resulting in an optimal set of PID controller settings. For a time the controllers set and maintained the control variable 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. This indicates that the population-based meta-heuristics performs better than the single point search methods. GA and ACO show better performance than FA. It also indicates that TS results are comparable to those of FA. The results show that SA and TA algorithms failed to solve the PID controller tuning problem.*

DOI: 10.4018/978-1-4666-4450-2.ch007

## INTRODUCTION

In the last 20 years, a new kind of approximate algorithm has emerged which basically tries to combine basic heuristic methods in higher level frameworks aimed at efficiently and effectively exploring a search space. These methods are nowadays commonly called *meta-heuristics*. The term *meta-heuristic*, first introduced in (Glover, 1986), derives from the composition of two Greek words. *Heuristic* derives from the verb *heuriskein* (euriskein) which means “to find”, while the suffix *meta* means “beyond, in an upper level”. Before this term was widely adopted, meta-heuristics were often called *modern heuristics* (Reeves, 1993).

Optimization heuristics are generally divided into two broad classes, namely, constructive methods and local search methods. For a long time local search has not been considered as a mature technique and only recently the method has become an object of increasing interest (Gilli & Winker, 2009). Local search methods are divided into trajectory methods (single point search) and population-based methods. Population-based meta-heuristic methods combine a number of solutions in an effort to generate new solutions that share good merits of the old and are expected to have better fitness. Such methods are iterative procedures that gradually replace solutions with better found ones. This class of algorithms includes but is not restricted to Ant Colony Optimization (ACO) (Dorigo & Stutzle, 2004; Dorigo & Socha, 2007; Bianchi et al., 2009), Evolutionary Computation (EC) including Genetic Algorithms (GA) (Goldberg, 1989), Particle Swarm Optimization (PSO), Firefly Algorithm (FA) (Yang, 2008; Yang, 2009). On the other hand, single point search methods improve upon a specific solution by exploring its neighborhood with a set of moves. Examples of this class are Simulated Annealing (SA) (Kirkpatrick et al., 1983; Metropolis et al., 1953), Thresholds Acceptance (TA) (Dueck & Scheuer, 1990) and Tabu Search (TS) (Glover

& Laguna, 1997; Gendreau, 2002; Gendreau & Potvin, 2005; Gendreau & Potvin, 2010).

During the last decade, meta-heuristic techniques have been successfully applied to a variety of areas, including to bioprocess engineering (Roeva, 2010; Angelova & Pencheva, 2011; Angelova, Tzonkov, & Pencheva, 2011; Roeva & Fidanova, 2012; Angelova & Pencheva, 2012a; Angelova & Pencheva, 2012b; Roeva & Trenkova, 2012; Kosev et al., 2012; Angelova, Atanassov, & Pencheva, 2012a; Angelova, Atanassov, & Pencheva, 2012b; Roeva, 2012; Angelova, Melo-Pinto, & Pencheva, 2012; Roeva, 2013; Angelova & Pencheva, 2013; Roeva & Fidanova, 2013). In this work a list of meta-heuristic methods is applied to an optimal tuning of a digital Proportional-Integral-Derivative (PID) controller. The controller is used for control of glucose concentration during an *E. coli* MC4110 fed-batch cultivation process.

Cultivation of recombinant micro-organisms (e.g. *E. coli*), in many cases is the only economical way to produce pharmaceutical biochemicals such as interleukins, insulin, interferons, enzymes and growth factors. To maximize the volumetric productivities of bacterial cultures it is important to grow *E. coli* to high cell concentration. Among the different modes of operation, (batch, fed-batch, and continuous), fed-batch operation is the one most often used in industry. Since both nutrient overfeeding and underfeeding is detrimental to cell growth and product formation, development of a suitable feeding strategy control is critical in fed-batch cultivation. The control strategy for substrate feed rate can be summarized in three groups: open (feedforward), closed-loop (feedback) control and mixed (feedforward-feedback). In feedback control of industrial cultivation processes, the PID controller is widely used.

When the object is characterized with significant time delay the conventional PID controller can not ensure the control system performance. A tool approved in the practice for time delay compensation is the Smith Predictor (SP) (Smith, 1959). In this predictor scheme, the mathematical

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