



## THE DETECTION OF ANOMALIES IN CONTROLLING OF THE COMBUSTION PROCESS BY USING A GENETIC ALGORITHM

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### Summary

The article presents the problem of dynamically changing fuel quality during the control of combustion process. The way of the measurement process variables related with this process was described. In the next part of the article schematics, ideas and genetic algorithm were presented by the author. They are also presented conditions in which the above anomaly detection algorithm perform in the regulation of combustion. The results of these solution were presented in the final section.

Keywords: Genetic algorithm, diagnose, anomaly detection.

### DETEKCJA ANOMALII W STEROWANIU PROCESEM SPALANIA ZA POMOCĄ ALGORYTMU GENETYCZNEGO

#### Streszczenie

W artykule przedstawiono problem związany ze zmieniającą się dynamicznie jakością paliwa podczas sterowania procesem spalania. Opisano sposób pomiaru zmiennych procesowych związanych z tym procesem. W kolejnej części artykułu autor przedstawił schemat, idee oraz działanie algorytmu genetycznego. Zostały również przedstawione warunki w których powyższy algorytm realizuje detekcje anomalii w procesie regulacji spalania. W ostatniej części został przedstawiony rezultat zaproponowanego rozwiązania.

Słowa kluczowe: Algorytm genetyczny, diagnostyka, detekcja anomalii.

## 1. INTRODUCTION

Observing recent developments of artificial intelligence methods which applies in the diagnosis of industrial processes, it can be seen that for some time sought are ways solutions to difficult problems based on natural mechanisms occurring in living organisms. Using the acquired knowledge during research on biological evolution of living forms, he formed one of the methods of artificial intelligence, which is called evolutionary algorithms[1]. Genetic algorithms which are a subset of evolutionary algorithms are based on the mechanism to modify the genetic material of new individuals in such a way that they are better adapted to the conditions of life (environment) than their parents. The mode of action of the genetic algorithm and advanced computational techniques used in the proposed solution are presented later in this paper.

## 2. DEFINITION OF THE PROBLEM

One of the important problems encountered in controlling the combustion process is dynamically changing fuel quality, which is being supplied a source of heat. This is due to the use of coal dust of different calorific values and co-firing biomass[2][3]. The problem comes, so that fuel is loaded into the boiler from different places of fuel square, which is heterogeneous and having different calorific values differently burns. The calorific value of the fuel can be expressed by the relationship represented by the formula 1[4]:

$$Q_{\omega}^r \approx 339,1C + 1214,2(H - \frac{O}{8}) + 104,7S - 25,12W_c; \quad (1)$$

where  $Q_{\omega}^r$  – calorific value of the fuel,  $W_c$  – it is the total fuel moisture, which is the sum of moisture hygroscopic and moisture transient.



Fig. 1. The boiler type WR-25

As described in this article below case we are dealing with control of the combustion process in the boiler water grate type WR-25 (Fig 1), made in the technology of tight walls using controller S7-300. The process takes place in the heat DPM belonging to the Municipal Heating Company in Koszalin. It is noted here that there is a phenomenon that has a significant impact on the effectiveness of control of this process. It consists in the fact that when fuel of different calorific value caused by different moisture transient, which is supplied to the combustion chamber, we have to deal with prolonged regulate the water temperature setpoint for power district heating network. This is due to the outdated method of calculation of normal values of process variables by which we understand the signals of known values and that are calculated by the automation system. Currently calculation of these values presented take place using the mechanisms regulating proportional- integral-derivative-based boiler output table, which describes the relationship between the parameters of the boiler [5][6]. Therefore, in this paper, the author focuses on a precise search of anomalies phenomena, in other words deviations from the values of normal in control of that same process. The analysis was one of the parameters affecting the combustion process, i.e., a pressure blowing air delivered to the combustion chamber. Measurements were made using a telemetry system, which is described in [7]. The results are presented in table 1.

Table 1 The measured value of the process variable

Number of measurement	The pressure of the blow of air delivered to the combustion chamber [kPa]
1	0,56
2	0,58
3	0,58
4	0,61
5	0,64
⋮	
15	0,92
16	0,93
17	0,95
18	1,10
19	1,11
20	1,14

The nominal value of the calorific supply to boiler type WR-25 is 25 000 kJ/kg. The algorithm was used to look for anomalies in the behavior of the control system with a very low calorific value fuel of 22 000 kJ/kg, for a given flow temperature of the district heating network of 110°C. The author assumed there will be processed direct task parameters and search for solutions will be using the following algorithms.

### 3. THE APPLICATION OF GENETIC ALGORITHM

One of the many features of genetic algorithms is that they allow you to effectively search a large solution space [8]. So, we use it to detect anomalies, using the procedure specified in figure 2. For this purpose we will look for a linear function described by formula 2 with a certain precision  $\gamma$ .

$$F(z) = -a \cdot z + b; \quad (2)$$

where “a” and “b”  $\in \mathbb{R}$ ,  $1 < a \leq 2$ ,  $1 < b \leq 2,3$ ,  $z$  – the measured value of the process variable.

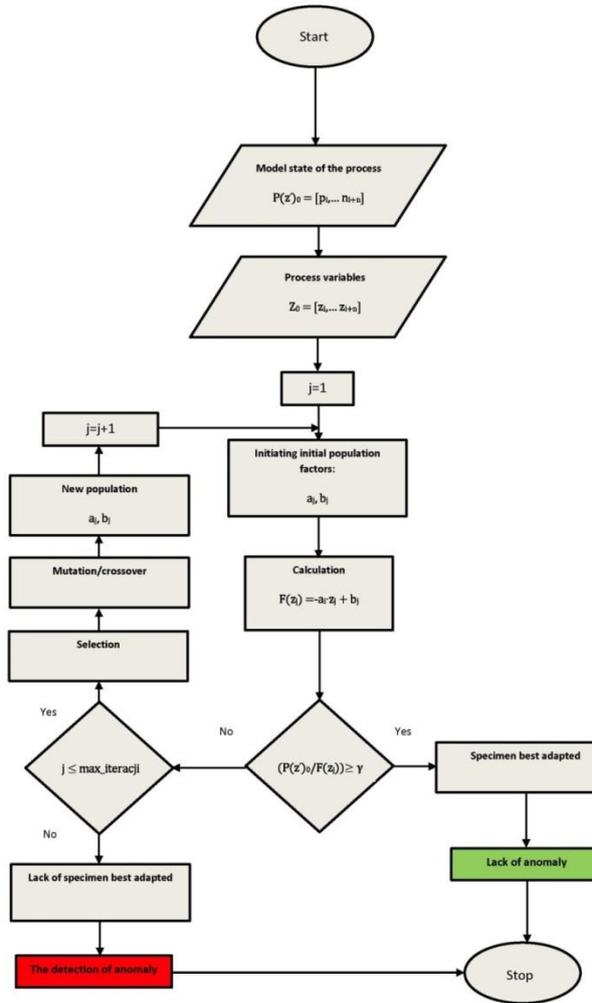


Fig. 2. The genetic algorithm

On the basis of the assumptions built into the formula above initial population and the slope of the intercept functions are presented and assessed adaptation of taking advantage of the church of process variables that are included in table 1. They also searched the variable function  $F(z)$ .

Evaluation specimens involves checking depending described by formula 3:

$$\frac{P(z')}{F(z)} \geq \gamma; \tag{3}$$

where  $\gamma=1,5$  – defined threshold of tolerance quotient of the standard and the search function,  $P(z')$  – it is a standard function describing the pattern of behavior of a control system which is represented by formula 4 and figure 3.

$$P(z') = -2 \cdot z' + 2,3; \tag{4}$$

where  $z'$  – the parameters of pattern of state of the process.

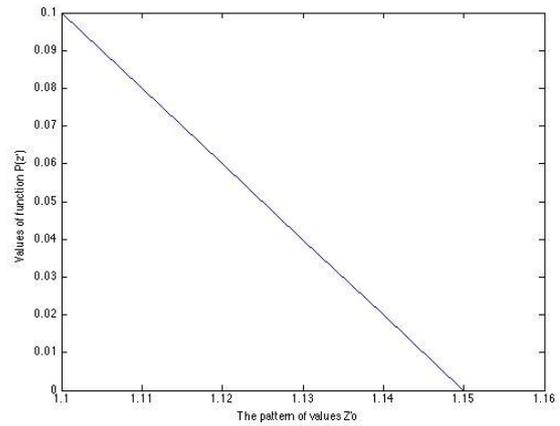


Fig. 3. Function of pattern state of control of pressure of the blow of air delivered to the combustion chamber for the low fuel quality

For the maximum number of iterations equal 100 following operations of genetic algorithm were performed [9]:

- Selection:

Applied tournament selection, which involves selecting random from the entire population of a few individuals (it is called: group tournament), and later with the group elected an individual of the fittest and prescribed it to the newly created population. The draw for the tournament and their selection of the best individual repeated until the creation of a whole new population[10].

- Mutation:

Performed uniform floating point mutation, where chromosomes "a" and "b" represent a collection of actual values  $x_k$ ,  $k=1, \dots, N$ ,  $z_{zn} x = [x_1 \ x_2 \ x_3 \dots \ x_N]^T$ .

Drawn number of  $k$  in the range  $[1, N]$  and the  $x_k$  mutation was carried out in accordance with the model no. 5:

$$x' = [x_1 \ x_2 \ x_3 \dots \ x'_k \cdot x_N]^T; \tag{5}$$

where  $x'_k = x_k^d + w_k(x_k^g - x_k^d)$ ,  $w_k$  – it has been randomly selected between  $[0, 1]$ ,  $x_k^d$  and  $x_k^g$  – are the lower and upper limits of the variable  $x_k$ .

- Crossover:

Performed linear combination of the two parental chromosomes according to the dependencies shown below:

If  $p^t < p_k$  then:

$$\text{Posterity} = \begin{cases} \text{ch1}^{t+1} = g \cdot \text{ch1}^t + (1 - g) \cdot \text{ch2}^t \\ \text{ch2}^{t+1} = (1 - g) \cdot \text{ch1}^t + g \cdot \text{ch2}^t \end{cases} \quad (6)$$

where  $g$  – is selected at random depending on the age of the population.

In the described anomaly detection algorithm, we can talk, if performing operations described above do not find the value of "a" and "b" for which 100 iterations described formula 2 quotient is greater than the threshold set by the author. Then we feel that the algorithm coincided to a satisfactory solution and subsequent iterations contribute little to the result.

#### 4. THE RESULTS OF THE ALGORITHM

In figure 4 shows the result of the actions of a genetic algorithm. It presents the obtained values of the function  $F(z)$  for the best chromosome "a" and "b". Thanks to the solution found 17 values of this function indicated in the figure as "o", which correspond to an "anomaly detection" and the 3 values marked with "\*", showing the correct state of combustion control in conditions of reduced calorific value of the fuel. According to the below figure, it can be concluded that the proposed solution is working properly.

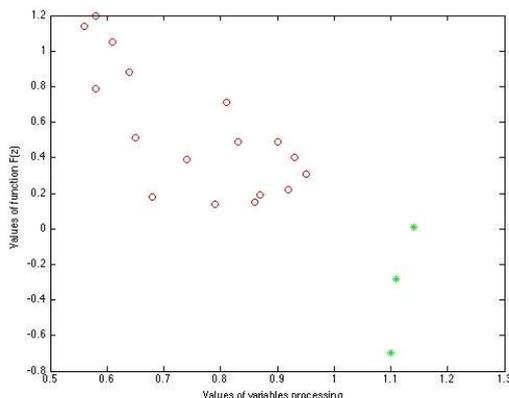


Fig. 4. Search function

The use of a genetic algorithm in the above embodiment shows that the value of the search function  $F(z)$  for the state of "Lack of anomaly"

may also assume negative values. This means that using the formula specified in the formula 3, we can use a stream of air delivered to the combustion chamber with values above 1,15 kPa. For example, for the air pressure of 1,17 kPa,  $F(z)$  is -0.06. As practice shows the use of larger air flows than assumed in figure 2 would not improve the combustion process, only it causes adverse event flue gas loss. The bottleneck of this solution is also the air blowing fans, which have a limited capacity. Some difficulty for the author was a choice of factor tolerance  $\gamma$ . Due to the relatively small number of process variable measurements to determine its value was used to search all possible states and rejected those for which the assessment of adaptation chromosomes "a" and "b" (model 2) produced inaccurate results. For the presented problem specified time computational complexity, which is reflected in the number of dominant operation to be performed to  $n$  data to obtain a solution. Through the operation of the parent we understand the task, whose performance directly affects the execution time of the algorithm. In this case, the operation accepted by the dominant quotient times the calculations presented in formula 3 and the genetic operations as: selection, mutation, crossing. Since the quality of code and speed of the computer on which algorithm is performed are qualities difficult to evaluate. A feature enabling the evaluation of the algorithm in terms of execution speed is the size of input data. It can be seen that for each subset of "n" input algorithm takes a fixed number of operations dominant. Execution time of the algorithm is proportional to the number "n" of input data raised to the power "X", which is constant at any value. So we have to deal with the complexity of computing polynomial expressed by formula 7[11]:

$$O(n^X); \quad (7)$$

where  $n$  - number of input,  $X$  - the number of operations prevailing in the algorithm

It should be noted that the time at which the algorithm reaches a solution also depends on other factors such as: the type of initial population, the parameters of genetic operators[12]. Due to the limited impact of the author ignored the complexity of computational iterations of the algorithm. Course of the computational complexity of the genetic algorithm is shown in figure 5.

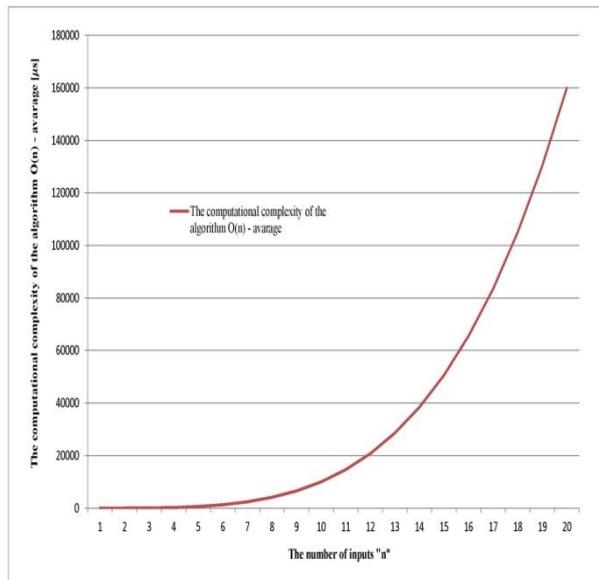


Fig. 5. Course of the computational complexity of the genetic algorithm

## 5. CONCLUSIONS

During the study and observation, it was found that the binary encoding does not guarantee a good correlation between job space and the space of representation. This is due to the fact that there is then a need for long binary strings for the tasks at the desired high dimensional accuracy. The success achieved by the appropriate choice of the objective function. It can be concluded that the method of artificial intelligence, which are evolutionary algorithms is relatively fast: finding a solution it is often possible after reviewing a surprisingly small portion of the state space. Analyzing the computational complexity of the proposed method of diagnosis it can be concluded that increasing the amount of input data algorithm efficiency decreases. Therefore, a solution based on genetic algorithm can't be implemented in industrial applications and therefore you should look for other ways to set out in item 2 problem.

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