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THE DETECTION OF ANOMALIES IN CONTROLLING OF THE COMBUSTION PROCESS BY USING A NEGATIVE SELECTION ALGHORITHM

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Summary

The purpose of this paper is to present one of the ways to resolve the difficulties encountered during the use of the classical process control. The article presents the problem of a dynamically changing quality of fuel delivered to the water- grate boiler type WR-25, in which the combustion process takes place. The method of the measurement process variables related to this process was described. In the next part of the article, the author presents the basic concepts related to the natural immune system, and also introduces the scheme, ideas and a negative selection algorithm. Also, the conditions were presented in which the proposed algorithm performs a detection of anomalies in the regulation burned. The solution of the problem and the results of the proposed solution where presented in the final section of the article.

Keywords: The boiler, combustion, control, negative selection algorithm, diagnose, anomaly detection.

DETEKCJA ANOMALII W STEROWANIU PROCESEM SPALANIA ZA POMOCĄ ALGORYTMU SELEKCJI NEGATYWNEJ

Streszczenie

Celem niniejszej publikacji jest przedstawienie jednego ze sposobów rozwiązania trudności występujących podczas zastosowania klasycznego sterowania procesem spalania. W artykule przedstawiono problem związany ze zmieniającą się dynamicznie jakością paliwa dostarczanego do kotła wodno-rusztowego typu WR-25, w którym odbywa się proces spalania. Opisano sposób pomiaru zmiennych procesowych związanych z tym procesem. W kolejnej części artykułu autor przedstawił podstawowe pojęcia związane z naturalnym systemem immunologicznym, a także przedstawił schemat, idee oraz działanie algorytmu selekcji negatywnej. Zostały również przedstawione warunki w których zaproponowany algorytm realizuje detekcje anomalii w procesie regulacji spalana. W ostatniej części artykułu zaprezentowano wyniki działania zaproponowanego rozwiązania.

Słowa kluczowe: Kocioł, spalanie, sterowanie, algorytm selekcji negatywnej, diagnostyka, detekcja anomalii.

1. INTRODUCTION

The immune system is a complex biological system, that features a rapid defense mechanism against foreign structures know in medicine antigens [1]. Natural defense mechanism, which can be observed in living organisms, have become an inspiration for new artificial intelligence methods which are artificial immune systems. They imitate the ability of specific immunity (adaptive) by the detection rate of emerging antigens, as well as storing information about those antigens with have already been identified. By understanding immune mechanisms, an effective system was created of distributed data processing with an ability to learn. While working on the Artificial immune systems, two basic algorithms were developed: the clonal selection (CLONAG) and the negative selection. Owing to the characteristics described above, they are being increasingly used for advanced diagnostic tasks. In next part of the publication, the author presents the use of the classical negative selection algorithm to diagnose the state of combustion control in industrial conditions.

2. DEFINITION OF THE PROBLEM

One of the important problems encountered in controlling the combustion process is a dynamically varying fuel quality, which is powered by a heat source. This is due to the use of coal dust of different calorific values and co-firing of biomass[2][3]. A problem occurs, namely that the fuel is loaded into the boiler from different places of the fuel square, which is heterogeneous and has different calorific values, and burning occurs in a different manner. The calorific value of the fuel can be expressed by the relationship represented with Formula 1:[4]

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

where Q^r_ω – calorific value of the fuel, W_c – it is the total fuel moisture, which is the sum of moisture hydroscopic and moisture transient.

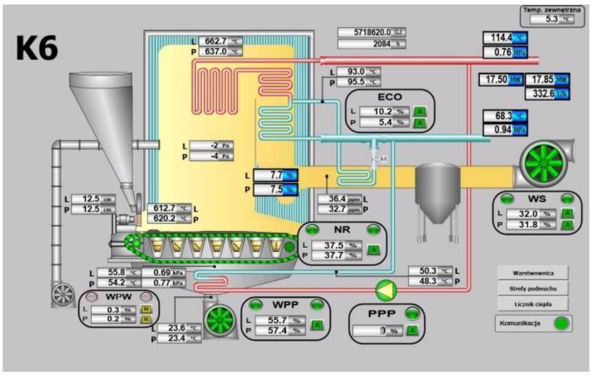

Fig. 1. Vizualization of the work of stocket fire boiler type WR-25 (Softechnik 2013) where WPP - the primary air flow, WPW - secondary air flow, NR - propulsion of grate, WS - extract fumes

As described in this article below, we are dealing with control of the combustion process in the boiler water grate type WR-25, made in the technology of tight walls using the S7-300 controller. The process takes place in the heat DPM that is owned by the Municipal Heat Plant in Koszalin. It is noted here that there is a phenomenon that has a significant impact on the effectiveness of the control of this process. It consists in the fact that because of the fuel of a varying calorific value due to a different moisture transient, which is supplied to the combustion chamber, we have to deal with an extended temperature setpoint to regulate the flow in the district heating network. This is because there is an instability in the form of deviations (up and down) at the outlet of the boiler water temperature [5]. This is due to the outdated calculation method of the normal values of process variables through which we understand as the signals of known values and that are calculated by an automation system. Currently, the calculation of these values takes place using mechanisms that regulate the 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 in the phenomena, in other words deviations from normal values in the control of that same process. The analysis was one of the parameters affecting the combustion process, i.e., the pressure of the blow of air delivered to the combustion chamber. Measurements were made using a telemetry system with the visualization of heat source work (Fig. 1). It is a User-Configurable Open System, which works by simultaneous co-operation of the Distributed Control System with the Programmable Logic Controller which was described in [7][8][9]. This system enables remote measurement of the basic operating parameters of the heat source, and also to set the desired values depending on the needs. The measurement results obtained according to the blast pressure of the air delivered to the combustion chamber and the resulting temperature at the outlet of the boiler are presented in Figure 2.

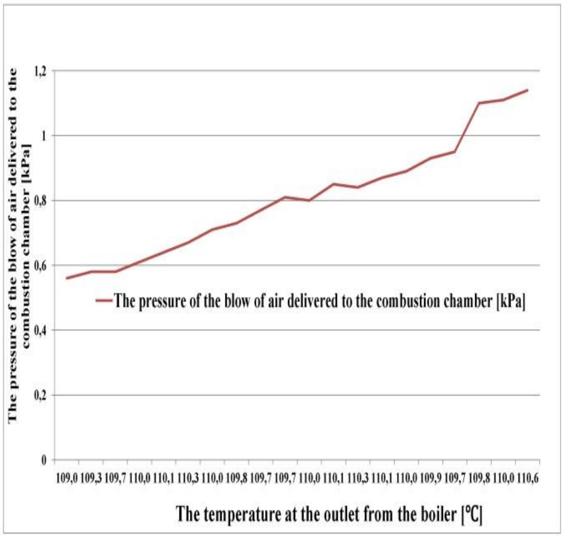

Fig 2 The chart pressure of the air delivered to the combustion chamber and the resulting temperature at the outlet of the boiler

The nominal value of the calorific supply to the 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℃.The author assumed that the process will direct the task parameters, and the search for solutions will be using the algorithm presented in the next section of the article. An analysis of the power array of the boiler demonstrated that for a very low calorific value of the fuel pressure of the blow of air delivered to the combustion chamber a linear function can be used described with Formula 2.

$$P(n') = -2\cdot n'+2{,}3; \quad (2)$$

where n' is the parameters of the pattern of the process state.

Using the above formula, we may obtain the pattern value of this parameter, which we will use later in the article, as one element of the negative selection algorithm. Table 1 shows the result of these calculations.

Table 1 Pattern of state of combustion process control for low fuel quality

Value of function P(n)	The parameters of pattern of the process state - n'
0,10	1,10
0,08	1,11
0,06	1,12
0,04	1,13
0,02	1,14
0,00	1,15

3. THE APPLICATION OF NEGATIVE SELECTION ALGORITHM

The negative selection algorithm (Fig. 3) [10] next to the clonal selection algorithm is one of two solutions which make up the artificial immune systems, and it is based on a mechanism of an elimination of those cells that recognize their own structures [11].Therefore, its use is mainly limited to the detection of anomalies of such problems in security systems, or manufacturing processes, as it is in the case described above[12][13].

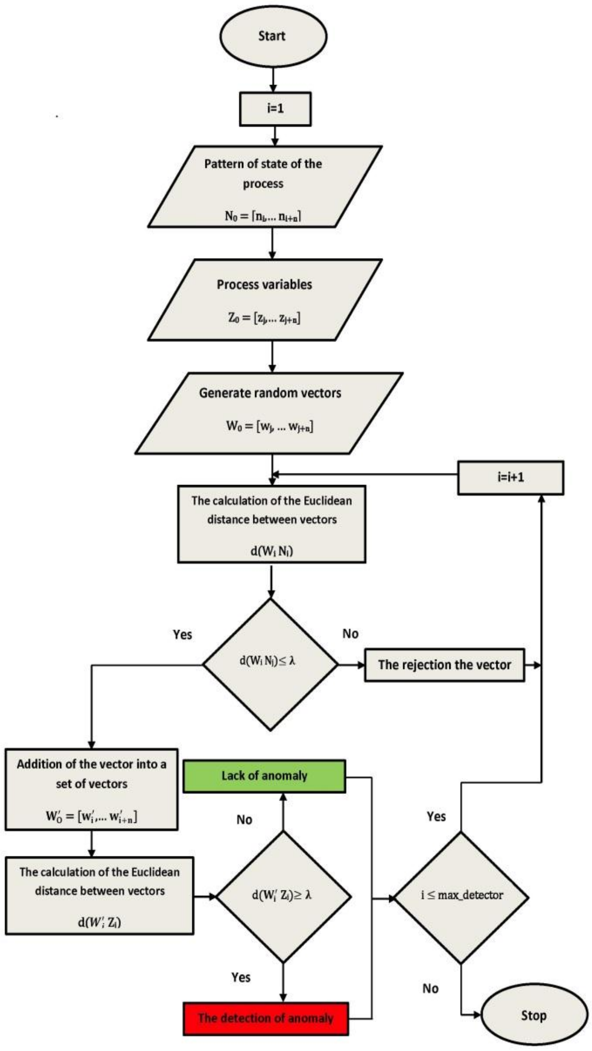

Fig. 3. Negative selection agorithm

To understand this algorithm, we have to assimilate some concepts of medicine and the immune system of living organisms. The solution will use a mechanism for specific immunity (adaptive), which uses two types of immune cells: - cells T and B [14]. Because they do not show any significant differences in terms of construction, but only different locations in the body, the author used the type B cells, the model shown in Figure 4[15].

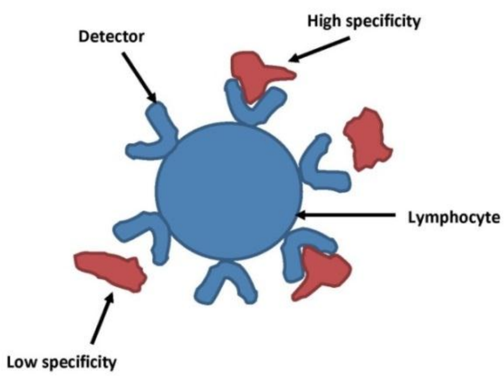

Fig. 4. Model of lymphocyte

In the problem described, we will be talking of an alien pathogen that threatens the structure of the body - in this case, it is a low calorific value fuel. Though, - it is an antigen, - this is an impressive immune response to a pathogen, which is the principal function of B cells, referred to as humoral responses. The process itself, in which the system learns to recognize a new antigen, is called a primary immune response. A negative selection algorithm in the sense of information technology operates on two sets of input: a set of the patterns its own structures and a set of randomly generated antibodies. In contrast, the output is obtained from the set of W_O' antibody (referred herein as detectors), which can only recognize a foreign structure[16].

The algorithm includes the following steps [17]:

- Generation of a random population of vectors W.
- Determination of the degree of matching of all individuals in the population with respect to all patterns (epitopes) n' shown in Table 1, using in this case the Euclidean distance, as described with Formula 3:

$$d(X_0, Y_0) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}; \quad (3)$$

where $x_i, y_i \in \mathbb{R}^N$.

if the matching degree of one individual from the population of W exceeds a certain threshold of tolerance λ it is removed and then we talk about low specificity, otherwise it is added to the resulting population that we call detectors. An evaluation of vectors is performed according to the equation:

$$d(W_i, N_i) \le \lambda; \quad (4)$$

where threshold $\lambda = 0{,}2$.

- The creation of the detectors of immune memory containing antibodies: $W_O' = \{w_1', w_2', \ldots, w_n'\}$
- Determination of matching antibodies from the collection W_O' with the values of process variables (Table 1) using the previously presented one as the Euclidean distance. Determination of the degree of matching of antibodies of the set W_O' with values measured the blow pressure of air delivered to the combustion chamber, as previously set forth using the Euclidean distance.:

$$d(W_i', Z_i) \ge \lambda; \quad (5)$$

If the dependency is fulfilled by Formula 3, we are then referred to the detection of anomalies in regulating the combustion process, and otherwise recognize that it runs properly. The operations described by the algorithm is performed to generate 500 random vectors defined as the parameter of "*max_detector*".

4. THE RESULTS OF THE ALGORITHM

In Figure 5 shows the result of the solution for the problem of detecting anomalies in controlling the combustion process, which is based on an artificial immune system. For the calculation of the Euclidean distance (Formulas 7 and 8), five numbers were used in the measurement windows of length. With 500 randomly generated sets of vectors 30 detectors were calculated marked "x" that recognize foreign structures, as well as 26 detectors marked "*" that recognize their own structures, and the rest were rejected as not meeting the criteria of the algorithm. The congregation of 30 detectors from the interval of {0,9; ...; 1,0} is both specific immune memory containing antigens (antibodies) used to recognize the pathogenic process variables. This solution was tested using the higher value of the pressure of air flow, that is 1,17 ÷ 1,18 kPa. In this case the Euclidean distances described in Formula 8 amounted to 0,32 ÷ 0,64 or the algorithm returned the value of "Lack of anomaly".

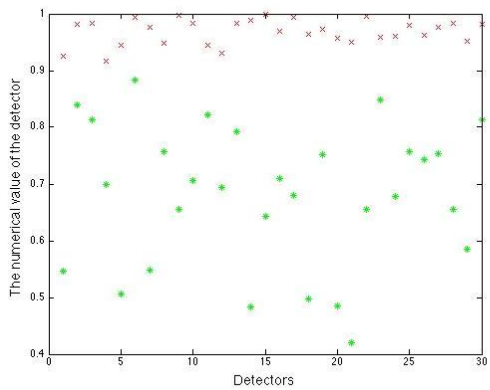

Fig. 5. Collection of all detectors found by negative selection algorithm, where "x" - the detectors that recognize foreign structure, "*" - the detectors that recognize their own structures

5. CONCLUSIONS

In the course of the observations conducted of the algorithm of negative selection, it was found that the use of its classic version allows a detection of anomalies on the level difference of 0,01 kPa of the diagnosed control parameter, which is a value sufficient, taking into account the very high dynamics of combustion in industrial conditions. Deviations from the top may be omitted due to the operation of the PID, which prevents larger blowing air into the combustion chamber. The choice of threshold λ was a decisive factor in the process of diagnosis using the negative selection algorithm.

Unfortunately, there is no satisfactory medium selection or calculation of its value and the author took an advantage of the method of search conditions in the range of 0,1 ÷ 1,0. It should also be noted that it will have different values for another water temperature setpoint for the power district heating network. The decisive factor for the convergence rate of the algorithm is the short length of the measuring window. It was observed that the lower it is the convergence of the algorithm is faster. The effectiveness of the algorithm requires, however, that it is not too small, so some optimum is needed. In this case the author obtained five numbers as the optimal length of the measuring window. For a comprehensive solution to the problem outlined in section 2, the application of the immune system seems to have no practical application, due to the inability to determine the calorific value of the fuel. The author is working on the merger outlined in this article, the negative selection algorithm with artificial neural networks, and fuzzy logic.

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