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OPTIMIZATION CONTROL SYSTEM USING EVOLUTIONARY ALGORITHM

METODA OPTIMÁLNÍ SYNTÉZY ADAPTIVNÍHO PID REGULÁTORU UZAVŘENÉHO REGULOVANÉHO SYSTÉMU S VYUŽITÍM EVOLUČNÍHO ALGORITMU

Abstract

This work suggests a method of searching optimal adaptive of controller PID in closed system using evolutionary algorithm. The object with well-known characteristics is controlled by a signal from the controller. Its' assumed answer step change of system will be well-known desirable time function of the basis we can characterize, regulate, answer of system depending on controller's PID parameters, and it calculates adaptive of this controller. Adaptive makes possible to obtain characteristics, which will be similar to assumed characteristics presented by time function. The answer of researched controller's system will be characterized by the best desirable quality index.

Abstrakt

V příspěvku je navržena metoda optimální syntézy adaptivního PID regulátoru uzavřeného regulovaného systému s využitím evolučních algoritmů. Objekt s dobře známou charakteristikou je řízen prostřednictvím akční veličiny z regulátoru. Adaptivní regulace umožňuje získat charakteristiky, které jsou velmi podobné předpokládaným časovým průběhům. Zkoumaný regulátor je charakterizován požadovaným indexem kvality.

1 INTRODUCTION

There is a fundamental problem in real systems control to selection of structure and regulator's parameter so to achieve the best, in given sense, criterion, the signal's course out-signal of the system. Many methods of selection regulator's arrangement exist e.g. Ziegler-Nichol's method or Passen's method [NOWAKOWSKI J., SUCHOMSKI P. 1988, TARNOWSKI W. 2001, VITEČKOVÁ M. 1999, VITEČKOVÁ M., JARACZ K. 2006]. In this paper a method of selection parameters of regulator's PID arrangements using evolutionary algorithm [MICHALEWICZ Z. 1999] is presented. The aim is a system control with feedback, with the regulator that makes a control signal. A signal controls a structure on the basis of error signal.

A structure and regulator in system first is considered.

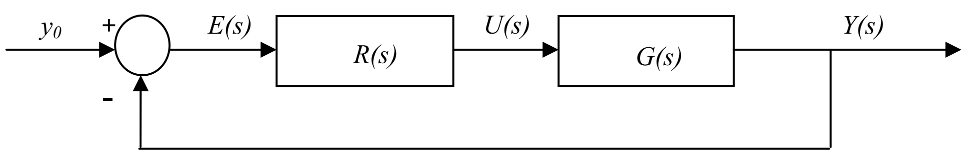

Fig. 1 Control system

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This system (Fig. 1) is described by equation:

$$\begin{cases} U(s) = R(s)E(s) \\ Y(s) = G(s)U(s) \end{cases}, \tag{1}$$

where:

$R(s) = f(k_R, T_d, T_i)$ – transfer function of the regulator PID,

$G(s) = f(k_g, T_1, ..., T_{n-1})$ – transfer function of the object,

U(s) – signal control's object and out-signal of regulator,

Y(s) – output signal of the object,

E(s) – error signal.

A control system is described by differential equation n-th order:

$$a_n \frac{d^n y(t)}{dt^n} + ... + a_1 \frac{dy(t)}{dt} + a_0 y(t) = b_2 \frac{d^2 y_0(t)}{dt^2} + b_1 \frac{dy_0(t)}{dt} + b_0 y_0, \tag{2}$$

where:

y_0 – signal task,

y(t) – out-signal of control systems,

$a_i = h_i(k_R, T_d, T_i, T_1, ..., T_{n-1})$, for *i=1,2, ... , n-1* as well as

$b_j = k_j(k_R, T_d, T_i, T_1, ..., T_{n-1})$, for *j=0,1,2* - constants dependent on regulator's parameter and control's structure, n – differential equation's range dependent on structure's range,

k_R - gain of the regulator,

T_d - differential action time of the regulator,

T_i - integral action time of the regulator,

k_g - gain of the object,

$T_1,...,T_{n-1}$ - time constant of the object.

The aim of consideration is to find such parameters k_R, T_i , T_d of regulator with known parameters: k_g, T_1 , ... T_{n-1} of object, that system's answer will meet task quality indexes, that are characterized by task control time and overshot.

Evolutionary algorithm makes the best fit of step answer into desirable form by selecting combination of regulator's parameters.

2 EVOLUTIONARY ALGORITHM

A general diagram of evolutionary algorithm is presented on Fig. 2 [HUDY W., JARACZ K. 2004, MICHALEWICZ Z. 1999].

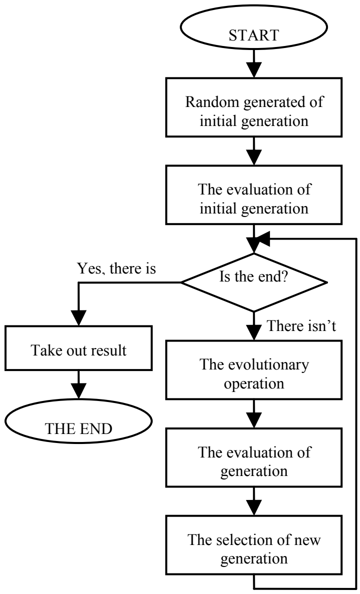

Fig.2 General diagram of evolutionary algorithm

- **Individual's representation**

In evolutionary algorithm (EA) the important part is acted out of the coding task's way. The best possible way is natural representation, i.e. the individual is represented by real number and it isn't necessary to decode of registered on data of individual's features.

- **Variable positionary mutation**

The mutation is operator, which changes insignificantly the individual's features. As a result of mutation's action one descendent is received from one procreator. The descendent should be located with most probability next to individual, which it arisen, and with smother probability – farther from it. But the operator must make it possible to create the descendent on how the most area, with the suitably selected probability.

- **Progressive variable positionary mutation**

This variety of mutation authors treat on agent way. The descendent, selected by random direction, improves his evaluation's function. If the step brings the positive result, i.e. it is get to increasing evaluation's function, that the step is retained, otherwise, the individual returns to the start point. This attitude should bring the result in action's end stage of evolutionary algorithm, when the all population is planed nearby the best solution. Insignificant, positive steps approach program to fit function's optimum.

- **Variable positionary cross**

The cross is a multiargument operator i.e. from many individuals, generally two, is created the descendent results. In this paper the cross operator makes on two individuals from population (parental individuals) and it creates one descendent individual.

- **Selection**

In sequence of considerations is using two selection's method. First of them is a roulette's method. The weight for the all individuals is counted so that better solutions have a bigger weight that worse ones. These weights are arranged to rising sequence. The sum of these weights is 1. Next numbers we draw from range <0,1>. There are so many numbers as are individuals of this population.

Then we choose individuals to create new population. By means of this selection's method a new population is chosen in the first half of algorithm time's action. During the second half of period individuals of the new population are chosen in the necessary way, and from each generation turned down are the worst individuals [MICHALEWICZ Z. 1999].

3 HYPOTHETICAL COMPUTATION OF REGULATOR'S PARAMETERS PID FOR THE SECOND RANGE SYSTEM USING EVOLUTIONARY ALGORITHM

For example is considered the procedure of regulator's parameters PID selection, in system control with object first range with using evolutionary algorithm of second range [JARACZ K., LUDWIN-ZIELIŃSKA J. 1984]:

$$a_2 \frac{d^2 y(t)}{dt^2} + a_1 \frac{dy(t)}{dt} + a_0 y(t) = b_2 \frac{d^2 y_0(t)}{dt^2} + b_1 \frac{dy_0(t)}{dt} + b_0 y_0, \tag{3}$$

where:

y_0 – isolated step about amplitude U.

There is an aim to define of regulator's parameters k_R, T_i, T_d for which control system is characterized by task time for answers. This time must equal t_0 to and overshot. We found that there are known object's parameters. Evolutionary program will look for the best result in the three dimensions of space. Each of individuals into population possesses features which clear-cut identify him. These features, which are evolutions objects, are regulator's parameters, i.e. k_R, T_i, T_d.

The adaptive's criterion is a sum of errors squared, which sum is described by equation (4) and is shown on Fig. 3.

$$D = \sum_{j=1}^{k} \left(y_{sk}(j) - y_{ae}(j) \right)^2, \tag{4}$$

where:

y_{sk} – task a priori step function response of control system,

y_{ae} – characteristic counted by evolutionary algorithm on basis of parameters k_R, T_d, T_i, k_g, T_1, ... , T_{n-1} ,

k – amount points, in which we count the difference of co-ordinates between characteristic y_{sk} and y_{ae}.

An evolutionary algorithm during calculations generates control system's characteristic of step function response for different value of controller's coefficient for each characteristic received in discreet time's moment. Error is calculated as a difference between abscise of calculated characteristic and demanded characteristic. The sum of error's squared on defined numbers of discreet time's moments makes up adaptive's criterion and it is assigned to each individual. Demanded characteristic is calculated only one time in the first phase of program on the basis of task parameters: answer's time t_0 and overshot κ.

$$y_{sk}(t) = U\left(1 - \frac{1}{\omega} e^{-\delta t} \left(\omega \cos(\omega t) + \delta \sin(\omega t) \right) \right), \tag{5}$$

where:

$\omega = \omega(t_0, \kappa)$,

$\delta = \delta(t_0, \kappa)$.

Evolutionary algorithm's parameters for described problems experimental are selected, Table 1.

Tab. 1 Evolutionary algorithm's parameters experimental selected.

Individual amount in population	200
Mutation amount	40
Progressive mutation amount	20
Cross amount	40
Generation amount	2000
Squared error	2
Amount of discreet time's parameters	100

Table 2 includes object's parameters.

Tab. 2 Object's parameters

Object's reinforcement - k_g	2
Time constans - T_1	0,3

It is assumed answer's time should amount $t_0=1s$ and overshot $\kappa = 5\%$. Demanded step characteristic change co-ordinates inserts into random – access memory. Simulation of controller's parameters carries out 20 times for the object of parameters, which are included on Table 2. Assumed precision is four decimal places. Results of calculations with the help EA are presented on Table 3.

Tab. 3 Index of results of calculations made with the help evolutionary algorithm.

Lp.	T_d	T_i	k_R	Fitness function
1.	1,4271	0,9790	4,8801	0,49690
2.	1,4259	0,9801	3,9310	0,49420
3.	1,4463	0,9693	4,3102	0,50343
4.	1,4851	0,9652	7,6016	0,52363
5.	1,5497	0,9573	8,1835	0,58193
6.	1,4828	0,9633	7,3256	0,50032
7.	1,5298	0,9632	4,7532	0,54221
8.	1,4400	0,9864	7,8498	0,52431
9.	1,3986	0,9632	10,111	0,58764
10.	1,3643	0,9975	5,5742	0,54097

For some calculated parameters, controllers made simulation calculate the step function response of system using MATLAB/Simulink language and it drew these characteristics (Fig. 3). On the Fig. 3 it drew characteristics indentified as control system, where appointed error was the smallest (Table 3, result 2), the bigger one (Table 3, result 9) and other selected result (Table 3, result 7). Variables T_d and T_i don't undergo changes for any of the received results. Variable k_R changes considerably its value, it's result of location of local function evaluation's minimums.

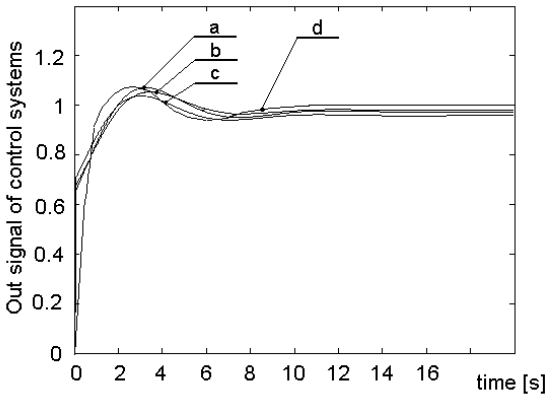

Fig. 3 Controls system's step function responses for results from Table 3: 9 (a), 7 (b), 2(c) and for demanded characteristic (d)

4 SUMMARY

Reasoning, which was presented here and the example of regulator's parameters of selection for I-st range's object don't confine the range of using evolutionary algorithms. It shows that proper evolutionary program may be useful in looking for PID regulator's parameters. Table 3. shows that received results are similar to each other and differences result most probably from evolutionary algorithm's character and from existence of local minimums of quality index. Quality index for controlled object of I-st range does never achieve a value equaled 0, and it means that demanded and calculated characteristics never agree. Control system characterized of assumed: answer's time and overshot.

REFERENCES

[1] HUDY W. & JARACZ K., *Identyfikacja obiektów wyższych rzędów przy zastosowaniu algorytmu genetycznego*, 32 Konferencja Automatyzacji Procesów Górniczych, Szczyrk 2004

[2] JARACZ K., ZIELIŃSKA J., VITEČEK A. & SMUTNY L., *Laboratorium Podstaw Automatyki*, Wydawnictwo Naukowe WSP, Kraków 1984

[3] MICHALEWICZ Z., *Algorytmy genetyczne + struktury danych = programy ewolucyjne*, WNT Warszawa 1999

[4] NOWAKOWSKI J. & SUCHOMSKI P., *Metoda optymalnego dopasowania modułu jako podstawa parametrycznej syntezy regulatorów*, PWN, Warszawa 1988

[5] TARNOWSKI W., *Projektowanie układów regulacji automatycznej ciągłych z liniowymi korektorami ze wspomaganiem za pomocą Matlab'a*, Wyd. Politechniki Koszalińskiej, Koszalin 2001

[6] VITEČKOVÁ M.: *Seřízení číslicových i analogových regulátorů pro regulované soustavy s dopravním zpožděním*, Automatizace, 2/1999, s. 106-111

[7] VITEČKOVÁ M. & JARACZ K.: *Controller-tuning method based on the desired control system model*. Annales Academiae Paedagogicae Cracoviensis, Studia Technica I, Wydawnictwo Naukowe Akademii Pedagogicznej, Kraków 2006

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