Adaptive robust control of oil and gas production objects

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Abstract. The article discusses a synthesis algorithm for objects with identification and parameter tuning. The algorithm is made on the basis of software and is tested for the formation of control effects in distillation column control circuit used in oil and gas processing production. It is shown that the control method suggested for a distillation column is not less effective in comparison with a control method that pre-tuned a preset proportional and integral differential controller. The suggested controller parameter tuning is not required and is made as the mentioned algorithm functions. Moreover, in the article it is possible to find the research results of testing in conditions of various level noise, control limitations, and controlled object parameter shift.

1. Introduction

Effective oil and gas production implies high requirements to the system of production technological processes. Despite adequately high potential of using modern automated control means in oil and gas production, some technological processes require sufficient involvement of experts and operators [1-4].

In many cases, technological process control formalization is very low, optimal control tasks in which controlling parameters choosing is required are solved by trial and error. When organizing highly effective production that implies reasonable use of non-human resources such as time and labour contribution, the situation like this is not acceptable. On the other hand, the use of sophisticated modelling and control systems, that embrace the whole physical and chemical core of technological processes, require significant expenses for computing infrastructure and specialist training, which at the present moment is unacceptable for many production enterprises and even might not be required [5-7].

It seems to be essential and timely to research and develop methods and algorithms that would allow identification and control of processes and equipment on the basis of adaptive fast models for small and fast software systems, as well as to further implement them. On the one hand, such models enable formation of control input in reasonable complicated technological processes with adequate quality. On the other hand, methods and algorithms that are adaptive allow structural and parametrical identification of models in automatic mode on the basis of selected controlled processes parameter observations [8, 9].

Considering the above mentioned aspects the article suggests using an adaptive algorithm, which is described in Section 1, solving sustainable control of oil and gas production equipment of processes. Section 2 of the article describes results of computational investigation of adaptive identification and control algorithm for the task of distillation column control in certain circuits.

2. Adaptive identification and control algorithm

Here adaptive identification system is analyzed [8, 10-13]. Here are experiment data about an object's input and output: $x(t)$; $x(t-1)$, $u(t-1)$; $x(t-2)$, $u(t-2)$; ... .

It is required using available selected observations of the object's input and output values to synthetize control computational algorithm $u(t)$ that assures minimal deviation of the system's output x from the set trajectory at each current moment of time t.

It is required to calculate controlling action $u(t)$ in such a way that it assures minimal deviation of the systems output x from the set trajectory $x*$ at each current moment of time t.

The authors accept that the object's behavior in a dynamic mode is described by the difference equation of:

$$x(t) = f(x(t-1), u(t-1), a) + \xi(t). \tag{1}$$

Sccept that $f(x(t-1), u(t-1), a)$ is a known function, a is unknown parameters, $\xi(t)$ is white noise in order to make calculation easier.

The authors made the object's model:

$$y(k \mid \alpha(t)) = f(x(k-1), u(k-1), \alpha(t)). \tag{2}$$

Here $y(k \mid \alpha(t))$ is the model's output at a moment time k at parameter vector's value $\alpha(t)$ calculated at a moment of time t.

This model is used for identification of parameters $\alpha(t)$ (identification algorithm is analyzed below) and for control input calculation. If $k = t+1$ we get the estimated object's output for the next moment of time:

$$y(t+1 \mid \alpha(t)) = f(x(t), u(t), \alpha(t)). \tag{3}$$

Parameters $\alpha(t)$ act as an identifiers, where they are calculated using the adaptive algorithm. Unknown control $u(t)$ is calculated on the condition of the best approximation of the model's output $y(t+1 \mid \alpha(t))$ to the desired trajectory $x*(t+1)$ at a moment of time $(t+1)$:

$$I(u) = (y(t+1 \mid \alpha(t)) - x*(t+1))^2 = \min_{u(t)\in U(t)}, \tag{4}$$

where $U(t)$ is a set of admissible control values, a particular example of which may be the interval of $[u_1, u_2]$. Thus based on the local optimality criterion we calculate optimal control:

$$u(t) = \begin{cases} u_1(t), & if \quad v(t) \le u_1(t), \\ v(t), & if \quad u_1 < v(t) \le u_2(t), \\ u_2(t), & if \quad u_2(t) < v(t). \end{cases} \tag{5}$$

Value $v(t)$ ensures absolute minimum of the function $I(u)$ (limitations of u are not considered).

Adaptive algorithm for parameter tuning.

At each current moment of time t on the basis of calculations $x(t)$; $x(t-1)$, $u(t-1)$ is corrected by the following algorithm (a simple adaptive algorithm):

$$\hat{\alpha}_i(t) = \hat{\alpha}_i(t-1) + \frac{(x(t) - y(t \mid (\alpha(t-1))))}{\sum_{i=1}^{n} \omega_i^2} \omega_i, \quad i = \overline{1, n}, \tag{6}$$

where $n-$ is a number of model parameters, ω_i is sensitivity function:

$$\omega_i = \frac{dy(t)}{d\hat{\alpha}_i}. \tag{7}$$

If system parameters are unsteady, we accept that the change in them adheres to a known equation:

$$\alpha(t) = f(\alpha(t-1)) \tag{8}$$

Then the formula of parameter tuning by the adaptive algorithm is as follows:

$$\hat{\alpha}_i(t) = f(\hat{\alpha}_i(t-1)) + \frac{(x(t) - y(t\,|\,(f(\alpha(t-1)))))}{\sum_{i=1}^{n}\omega_i^2}\omega_i, \quad i = \overline{1,n}. \tag{9}$$

3. Software implementation of algorithms and its testing

When making this research, a software named ACID.exe (Adaptive Column IDentificator) was developed. It allows imitating functioning of an adaptive system which includes identification. The following actions may be made using this software:

- simulation of object observation;
- designing models of the observed control object with identification of the model's parameters using a simple adaptive algorithm;
- imitating object's adaptive control in order to come to a desired trajectory;
- variation of desired trajectory;
- variation of adaptive control time and noise level of data obtained from the control object.

As control input output pairs of distillation column, the following parameter was analyzed:

- overheat steam flow and column bottom temperature;
- water-to-air flow and column head temperature;
- column feed concentration and column head temperature;.

Object output $x(t)$ deviation from the desired trajectory $x^*(t)$ has been calculated as follows:

$$er = \frac{1}{n}\sum_{i=0}^{T} |\, x(i) - x^*(i)\,|, \tag{10}$$

where $T = 200$ is the time of object control.

For each research parameter set for each control channel and due to a random component (noise) in order to get the results, control actions were identified and modelled for 20 times. Further, statistical estimation of the results and their sustainability was made (using ANOVA method). The result tables show average values of deviation from the desired trajectory considering statistical significance of the results with confidence level of p=0.05.

In order to assess approach effectiveness in general, a series of experiments was made. For the purpose of this experiment series effectiveness of the discussed adaptive identification and control method was estimated in comparison to the used PID controller. It is worth mentioning that PID controller parameters were chosen in advance for each control circuit using automated tuning of Matlab software using full earlier created model of a distillation column in terms of discussed control circuits. This is surely quite labor-intensive process that requires use of special knowledge related to the technological process used for the distillation column. For the purpose of the discussed task, an average value of control error (shift from the desired trajectory) for the suggested adaptive algorithm is 0.97–1.02 in comparison with the error of earlier pre-tuned PID controller, which may be considered acceptable considering that preliminary identification of the object controlled by PID controller is required when each of the parameters changes.

After that, general effectiveness of the adaptive method of identification and control was confirmed. Further, a research related to estimation of sustainability in conditions of various data noise and change in control action variation type and range was made.

3.1 Experiments under conditions of different noise levels

At first it was a research of dependence of system's output shift x from the set trajectory $x*$ on observed object's data noise levels. Desired trajectory is constant equal to 8. The results of this part of experimental study are presented in Table 1.

Table 1. Result of experiments under conditions of different noise levels

Amplitude of applied noise, A	Average shift from the desired trajectory
0	0.161
1	0.572
2	1.067
3	1.605
4	2.884

The experiment showed that the value of average shift of the system output from the set trajectory increases together with the amplitude noise over the object output, which indeed is complies with the theoretical assumptions.

Observed dependence of the value of average shift from the desired trajectory on the amplitude of the applied noise is almost linear.

3.2 Experiments under conditions of different shapes of desired trajectories

The dependence of system output shift x from the set trajectory $x*$ on the share of the desired trajectory was explored. The results of this part of experimental study are presented in Table 2.

Table 2. Result of experiments under conditions of different shapes of desired trajectories

Shape of the desired trajectory	Average shift from the desired trajectory
Constant value equal to 8.	0.439
piecewise-constant Value: 3, if $0 \le t < 75$; 7, if $75 \le t < 135$; -2, if $135 \le t < 200$;	0.466

Type of studied desired trajectories has almost no effect on the dependence of the system output shift x from the set trajectory $x*$ on the shape of the desired trajectory. If the interval of admissible regulation is broad enough, shift from the set trajectory does not change when its type changes.

3.3 Experiments under conditions of different interval of control input

The study of dependence of system output shift x from the set trajectory $x*$ on limitations over the interval of admissible control input was also conducted. Noise amplitude $A = 0.5$.

The results obtained for different intervals of control input are presented in Table 3.

Table 3. Result of experiments under conditions of different interval of control input

Interval of admissible control input	Average shift from the desired trajectory
$-0.3 \le u(t) \le 0.3$	8.278
$-0.6 \le u(t) \le 0.6$	8.726
$-1 \le u(t) \le 1$	0.761
$-2 \le u(t) \le 2$	0.503
$-5 \le u(t) \le 5$	0.448

The results of the experiments show that when the interval of admissible regulation is narrow, the system cannot approximate to the set trajectory. In this case, almost all the time the control either adheres to the border values or zips from one border of the interval to another. When the interval of admissible regulation increases, it leads to a dramatic decrease of the system shift from the set trajectory. Further broadening of the borders of the admissible interval leads to significant decrease of the shift from the set trajectory.

3.4 Experiments under conditions of different interval of control input

The research of dependence of system output shift x from the set trajectory $x*$ on proximity of the model's start parameter values to the real object parameters. Noise amplitude $A = 0.5$. Desired trajectory was piecewise constant. The results of experiments under conditions of different initial object parameters deviation are presented in Table 4.

Table 4. Result of experiments under conditions of different initial object parameters deviation

Parameters deviation	Average shift from the desired trajectory
$\Delta = 0.5.$	0.322
$\Delta = 1.0.$	0.461
$\Delta = 1.5.$	0.539

On the basis of the research results it may be concluded that increase in shift of the model parameters from the real object parameters leads to increase in the shift of the objects output from the set trajectory. However, this increase is insignificant in comparison to the value of parameter changes. This shows that despite the significant shift of the model parameters, adaptive algorithm of parameter tuning allows in a certain amount of operation time to identify the model parameters that are close enough to the object parameters.

4. Conclusion

The article discusses and suggests an algorithm of control identification and synthesis for use in tasks related to identification of control actions for the equipment of oil and gas production in order to achieve target control trajectories. Discussed adaptive algorithm possesses a number of characteristics that allow ensuring effective model parameter tuning in order to identify reasonable values of control actions considering the equipment parameter changing. Mentioned parameter changes is highly typical for the equipment of oil-refining production, as well as other oil and gas production types, considering its physical and chemical processes.

Due to this, the use of adaptive identification and control methods seems as essential and timely in comparison with traditional methods that require certain procedures of regulator parameter tuning (for example, PID controller). It appears that the use of such fast, relatively simple methods for support decision making in control of oil and gas production equipment is possible without significant expenses for changes in soft and hard ware, since it may be operated on a standard personal computer. Active use of such methods allows increasing effectiveness of problem solution when controlling technological equipment and processes that till the present moment are unfortunately quite manually controlled at national oil and gas enterprises as well as in other industries.

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