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Heat and Energy Consumption Management of a Public Object

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Abstract: The present paper addresses the effects of market and seasonal changes in the cost of heat and energy resources on the financial self-sufficiency of a public object. As an example, we take a college, the most important link in educational institutions of Kazakhstan. Computer experiments in the MathCad 15 and MatLab 6.5 environments substantiate the need to calculate the share of an energy-saving budgetary compensator, the adjustments of which will reduce the loss of unplanned funds during the period of sharp seasonal cold snaps and achieve the financial stability of the management object - the college. The calculated data allow it possible to predict the amplitude-frequency characteristics of the control signal for smoothing jumps and disturbances in the adaptive control system at the optimal time. This allows to ultimately save college money and spend part of it on additional financial support for the educational process and increase teachers' salaries. The results showed that the introduction of resource saving technologies (heat, electricity, utilities, staff) contributed to the sustainable development of the institution.

Keywords: Adaptive automated management system, Adaptive management, Computer simulation modeling, Heat consumption, Stability, The two-link adaptive control system.

1 Introduction

Education in the colleges of the Republic of Kazakhstan is an important and promising direction for improving the business and innovative education of the country's population. The management structure of colleges is based on private entrepreneurship. The competitive environment in the field of special pre-university education requires the effective use of all creative and material resources of the college whose ultimate goal is to train demanded middle-level specialists in the field of innovative economics and banking informational systems. The high quality training of specialists is the most important advantage in the work of the admission committee of a private college, which defines its financial and economic sustainability and the prospects for the development of the educational institution. One of the components that negatively affects the effectiveness of college management is the consideration of unpredictable external factors: different levels of training for students, undifferentiated wages, spasmodic inflation of money, a reduction in the real incomes of teachers and higher tariffs for electricity, water, higher utility costs, etc. Computerization and informatization of teaching and educational processes, creation of modern microcontroller automated management of heat, electricity and other material resources of the college set the new tasks for adapting management of technical and economic parameters and indicators of the educational process to the realities of modern society [1]. It should be noted that, among all colleges of the country, there is no example of a fully computerized college that meets the standards of the digital society. Therefore, the study and application of mathematical and computer analysis methods of sustainability colleges in the Republic of Kazakhstan as a management object are an actual and poorly investigated problem in the theory of control.

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2 Materials and methods

In the scientific and technical literature and in legislative norms, the concept of an adaptive educational institution (i.e. school, college and university) is actively discussed. In the city of Karaganda, on the basis of the secondary school N27 under the auspices of the Ministry of Education and Science of the Republic of Kazakhstan, an experimental program "Adaptive School - School for All" has been implemented for more than 5 years. It aims to prepare and develop intellectual abilities for the various levels of training, mental and physical abilities of secondary school pupils [2,3]. Creation of technologies of inclusive education from the viewpoint of control theory is interpreted as the management of education with significantly fuzzy regulators requiring the creation of costly corrective and development methods as well as the corresponding payment for teachers. Thus, tough budgetary financing without appropriate adjusting regulators led this new and necessary project to the path of unsustainable development due to strong fluctuations in the financial and economic parameters of the school. Children with disabilities often do not obtain private elitist and specialized education in the school system. For compulsory secondary education, the decrease in the probability of fuzziness in the input parameters in the management of an established institution is discussed at the legislative level and the state legislatively creates a system of additional funding for children with disabilities. For secondary pre-university education, these standards haven't worked yet. When students with disabilities join the college, this institution must ensure, at the expense of its own resources, a quality education for all students, regardless of their abilities. Therefore, the definition of an adaptive college and the characteristics of modern development of society should be considered much broader. A more precise definition of adaptive college is reduced to three words - a digital adaptive college. The most important criteria for such educational institution are: availability of all conditions (ramps, elevators, special suites, places in canteens, parking lots and special means of electronic communication and transfer) for full-time training of students with disabilities, providing these places with individual ventilation and heating systems; availability of all information resources (portal, content, simulators of laboratory works, webinars, smart desk) for distance learning of students with limited opportunities; and availability of special financial, material and pedagogical resources for training and consultations in educational and counseling centers close to the residence of students with disabilities. Thus, to create a digital adaptive college, it is necessary to develop and constantly improve modern adaptive control systems of information, material and pedagogical resources for colleges using fuzzy microcontroller PID regulators [4,5]. The created mathematical model Smart-system should provide a stable, optimal and efficient management of all resources of the educational institution [6,7,8,9,10]. It should be noted that with the availability of distance learning facilities in the college, the number of students, either those with disabilities, or those who temporarily do not have opportunity to study internally. The most common adaptive control systems are automatic control system (ACS) with feedback [11], under the conditions that all parameters of the system are digitized and formalized [12,13]. The principle of operation of such automatic control system is based on the fact that from the vector of input signals r(t) (a test of knowledge of applicants, current and final control of knowledge, over normative heat, power consumption, decline in academic performance, attendance) to form the error vector e(t), the response vector c(t) is extracted, on the basis of which signal e(t) is calculated. This signal, using the control system (the college directorate), affects the managed controlled system - management object (college) until the error signal is zero. Figure 1 shows the ACS variants with feedback. This model and the model with a compensator can be acceptable to the technical elements of the college (Fig.2) and to the collective of the college whose effectiveness can be quantified as the ratio of the real functionality of the organization vector to the vector of its functionality as an "ideal" functional system. This ratio is designated by N.N. Moiseyev "as the amount of dissipation (dissipation, volatilization) of energy and a certain analog of this ratio is the coefficient of efficiency"[13]. The objective function of the adaptation

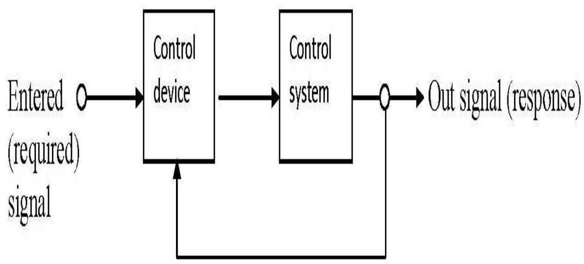

Figure 1: Control system with feedback

model should tend to minimum of the absolute difference between the vectors c(t) and r(t), provided that the poles of the transfer function of the entire system (college) are in the stability zone. This definition has a geometric interpretation and is easily calculated using the sisotool tools of the MatLab 6.5 software package [14]. One of the criteria for the stability of the transfer function and the system as a whole is the character of the location of the points on the complex plane of the roots of the

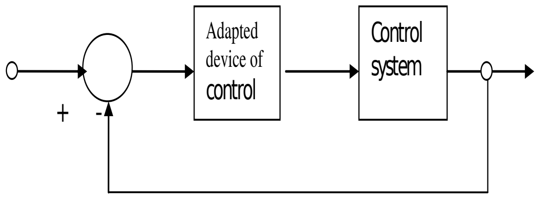

Figure 2: Control system with a single feedback and an adaptive series compensator.

characteristic equation. There are three variants of the location of the roots (Fig.3): all the roots lie in the left semi-plane (for example, p1, p2, p3, p4, p5, p6). The system is stable; at least one root lies in the right semi-plane (for example, p7). The system is unstable; the roots lie on the imaginary axis Ym and in the left semi-plane. The system is at the stability bound (conditionally stable).

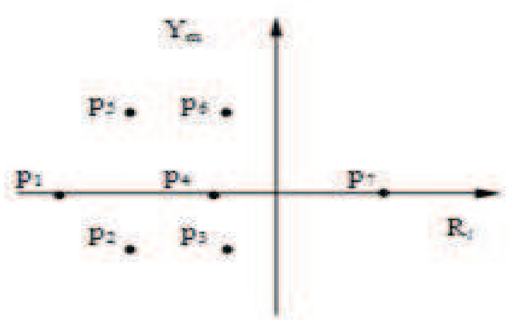

Figure 3: Variants of the location of the roots of the characteristic equation of transfer functions.

3 Results and Discussion

The control object (college) can not be studied as an adaptive system with fuzzy PID controllers unless the system is stable with feedback or with corrective elements [15]. We note that the content of the educational building, as a technical object, is the most important and costly component of the multi-linked management system of the college. Technological processes associated with the operation of the college's academic building are characterized by the presence of complex links such as "control-output" and "perturbation-output". We note that the algorithm for the implementation of the study of stability of college as an management object by means of the MathCad 15 software package have not been used anywhere. In particular, when applying a semi-empirical method based on the selection and evaluation of parameters of a controlled system by the least squares method, it is possible to restore the form of the transfer function. This allows to study all the complex processes which are characteristic for educational institution on the principle of "from a simple adaptive system to a complex multi-linked adaptive control system with fuzzy PID regulators." We consider, for example, the effect of overclocking curves of financial indicators of heat and power supply on the manageability and stability of the college as a two-link management system. Data on heat and electricity are obtained by processing the financial and statistical data of the financial and technical services of the college. It is known that there is no possibility to select analytically differential equations for the adaptive management of the material resources of the college, so the specific values of the coefficients of the transfer function are defined by the technical and economic indicators of the research object as well as the normative indicators of the material balance of heat and electricity flows, depending on the season and the time of year. The overclocking curves are taken from the financial and statistical data of the technical department of the college. When removing the acceleration curves on the "control-output" channel or processing the existing ones, it is necessary to monitor that the control and output values of the object are within the limits specified by the technical standards, the perturbations are constant and their values correspond to the intervals normalized for the selected periods of the year. Accordingly, the acceleration curves for each perturbation through the channels "perturbation-output" must be removed with a fixed control action and other constant perturbations. We give an algorithm for obtaining a transfer function. The curve for the acceleration of the discharge characteristics of the college is derived from the origin of coordinates as a function of time by training calendar (Fig.4).

Step 1. According to the overclocking curve, the tabulated values of the heat and power consumption data are compiled by the integral regulatory indicators, depending on the time of the year and day.

Step 2. By the form of the curve and the physical nature of the object, the possible orders of the left and right parts of the differential equation describing the object are selected.

Step 3. We describe the differential equation of the object in general form and the solution of the equation for a given input action.

Step 4. By the method of the least squares with respect to the reduced acceleration curve and the solution of the differential equation, the coefficients of the differential equation are defined. The graphs of the initial curve and the calculated curve are plotted.

Step 5. The transfer function is written by the differential equation.

It can be seen that the process of consumption of heat and electricity by the college is delayed due to the fact that in the first months of the school year, consumption

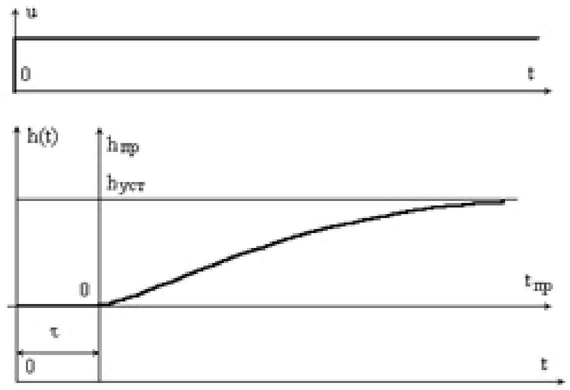

Figure 4: The change in input (student enrollment u) and the response of the control object to it are $h(t)$, where $h(t)$ is the energy consumption function to the standard h, h_o is the limit value of the relative energy consumption per student, τ is the time delay at the beginning of the school year.

Table 1: Table values of experimental data on the acceleration of costs for heat and energy consumption as a function of time t (training day), y is the relation of energy consumption on a student to standard (standard 4.00kW/month).

t	y	t	y	t	y	t
0.5	0.00	1.5	0.00	2.0	0.00	5.0
25.0	0.90	30.0	1.29	35.0	1.55	40.0
65.0	2.42	70.0	2.60	75.0	2.76	80.0
100.0	3.29	110.0	3.29	120.0	3.47	130.0
170.0	4.15	180.0	4.22	190.0	4.26	

y	t	y	t	y	t	y
0.00	10.0	0.00	15.0	0.02	20.0	0.90
1.67	45.0	1.68	50.0	2.01	55.0	2.26
2.85	85.0	3.00	90.0	3.08	95	3.1
3.64	140.0	3.79	150.0	3.93	160.	4.05

increases through a certain time interval τ, which is measured from the moment of the input signal change to the resource saving before the change of the output control signal begins. The delayed link is a link in which the output quantity y exactly repeats the input quantity x with some delay t: $y(t) = x(t - \tau)$. Transfer function of this link: $W(s) = e - \tau s$. Cutting out the first eight constant values corresponding to the pure delay with $\tau = 40$, we introduce the following values, starting the countdown of the time and the output quantity from zero.

Assuming that the curve corresponds to the transient process of a second order aperiodic link with a transfer function $W_0(s) = \frac{k_0}{(T_1 s+1)(T_2 s+1)}$, transient process can be described by expression $h(t) = k_0 \cdot \left(\frac{-\tau_1}{\tau_1-\tau_2} \cdot e^{\frac{-t}{T_1}} + \frac{-\tau_2}{\tau_1-\tau_2} \cdot e^{\frac{-t}{T_2}} + 1\right) \cdot u$, where $u = 4$ is the input effect, and k_0 is the transfer coefficient of the object. From the graph, the transfer coefficient of the object can be taken to be 1.1. Estimation of the unknown constants T_1, T_2, as well as a more accurate value of k_o provide the best approximation of the calculated curve $h(t)$ and the experimental acceleration curve given numerically can be obtained with the function $genfit(Vt,Vy,Vs,F)$ of the MathCad 15 package. This function returns the parameter vector T of the function F, which gives the minimum standard deviation of the function $F(t,...,T_n)$ from some function $y(t)$ given by the sets (vectors) of the values of Vy, Vt. The function F must be given in the form of a vector containing the function F itself in the symbolic form, and the expressions for all its derivatives with respect to the parameters T (including k_0, for which we introduce k_0 into the vector T), $u \geq 4 \quad \tau_0 = k_0$.

$$F(t,\tau) :=$$

$$= \begin{bmatrix} \tau_0(\frac{-\tau_1}{\tau_1-\tau_2} e^{\frac{-t}{\tau_1}} + \frac{-\tau_2}{\tau_1-\tau_2} e^{\frac{-t}{\tau_2}} + 1)u \\ (\frac{-\tau_1}{\tau_1-\tau_2} e^{\frac{-t}{\tau_1}} + \frac{-\tau_2}{\tau_1-\tau_2} e^{\frac{-t}{\tau_2}} + 1)u \\ \tau_0[\frac{-t}{\tau_1-\tau_2} e^{\frac{-t}{\tau_1}} + \frac{\tau_1}{(\tau_1-\tau_2)^2} e^{\frac{-t}{\tau_1}} + \frac{-\tau_1}{(\tau_1-\tau_2)\tau_1} e^{\frac{-t}{\tau_1}} + \frac{-\tau_2}{(\tau_1-\tau_2)^2} e^{\frac{-t}{\tau_2}}]u, \\ \tau_0[\frac{-\tau_1}{(\tau_1-\tau_2)^2} e^{\frac{-t}{\tau_1}} + \frac{1}{(\tau_1-\tau_2)^2} e^{\frac{-t}{\tau_2}} + \frac{t}{(\tau_1-\tau_2)\tau_1} e^{\frac{-t}{\tau_2}} + \frac{\tau_2}{(\tau_1-\tau_2)^2} e^{\frac{-t}{\tau_2}}]u, \end{bmatrix}$$

We prescribe the initial increment of the vector parameters $T0, T1, T2$ and consider the function $genfit(Vt,Vv,Vs,F)$, $VT := \begin{pmatrix} 1 \\ 1 \\ 4 \end{pmatrix}$, $TT := genfit(V_t,V_v,VF,F)$. We derive the vector of parameters T as $TT = \begin{pmatrix} 1.245 \\ 89.651 \\ 3.152 \end{pmatrix}$, the vector calculated values of the functions with concrete parameters T as $Y(t) := F(t,TT)_0$.

The transfer function of the object in increments considering the delay is $W_0(s) = \frac{k_0}{(T_1 s+1)(T_2 s+1)} e^{-s\tau}$, where $k_0 = 1.245, T_1 = 89.65c, T_2 = 3.15c$.

Thus, the transfer function of the two-link adaptive control system under consideration can be represented as $W_0(s) = \frac{1{,}245}{(282{,}3975 s^2 + 92{,}8s + 1)}$. The resulting transfer function allows computer experiments to be conducted to study the behavior of the control object (college) when external input parameters change (in our case, heat and power consumption). The adaptive automation system with feedback consists of two series-connected inertial links with one input and one output with a resulting transmission factor equal to 1.245 and time constants $T1 = 89.65$ and $T2 = 3.15$. To analyze and synthesize one-dimensional linear (linearized) adaptive systems for automatic control of college, we use the toolkit of the Control System Toolbox SISO (Single Input / Single Output) of MatLab 6.5. The results of computer experiments in the energy management process in the MatLab 6.5 prove the stability of the system for sharp external disturbances. As it is shown above, the dynamics of control of the two-tier adaptive system for managing heat and energy resources of the college has increased resistance to abrupt changes in energy consumption. However this result is achieved by additional financial costs for the purchase of resources.

4 Conclusion

The adaptive system for automated management of the process of heat and energy consumption by the college can be optimized through the rational use of heat and electricity. Smoothing sharp perturbing external factors of heat and power supply of the college allows smoothly and steadily regulates the consumption of these expensive resources within the given limits. Automated adaptive resource saving has a significant impact on the financial management of the educational institution; it allows to conduct modern scientific and technical measures for resource saving to attract additional funds for the adaptive learning process and increase the salaries of teachers.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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