INTEGRATION OF TWO-DIMENSIONAL CONTROL DEVICE IN INFORMATION TECHNOLOGY FOR SYSTEM SYNTHESIS

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Abstract. This article is devoted to the research and development of an innovative approach to the integration of a two-dimensional control device in the field of information technology for complex control systems. Complex management systems, including production processes, industrial installations and infrastructure, require effective solutions to optimize performance and reliability. The article discusses technologies and techniques that allow integrating a two-dimensional control device into information systems for more effective monitoring and management of complex processes. Special attention is paid to data analysis, signal processing and software development that can provide synergy between a two-dimensional control device and information technology. The study also addresses the issue of cybersecurity and data protection, as the integration of information technology and control devices can potentially face threats of cyber-attacks and unauthorized access.
Keywords: *two-dimensional control device, integration, information technology, synthesis of control systems.*

Introduction

In today's world, permeated with many complex systems and high technologies, the concept of control has become a key element in ensuring efficiency, reliability and safety in various fields, ranging from industrial production and energy to transport and medical fields. Complex control systems involve many variables, relationships and dynamic processes that require increasingly sophisticated tools and solutions to effectively control them. In the context of these challenges and requirements, this paper discusses an innovative approach to integrating 2D control into the information technology field to provide greater efficiency and reliability to complex process control systems. This is one of the current and promising areas of development that can change the paradigm of management and control in various industries. The article will focus on a practical example of research and implementation of projects that illustrate the potential of integrating a two-dimensional control device into information technology for complex control systems [1]. This example demonstrates the real achievements and benefits of this approach, and also points to possible directions for future development in this area. Research methods object of research in this work is the integration of two-dimensional control devices into information technologies in order to synthesize more efficient and adaptive control systems in various fields, including industrial production, transport, energy, and other complex systems.

Methodology

The research includes mathematical modeling of integration processes into information technologies and analysis of their interaction. Mathematical modeling allows you to create abstract models of control systems and information technologies for further analysis and optimization. To assess the effectiveness of integration and synthesis of control systems, the data analysis method is used. Which includes the collection, processing and interpretation of data obtained as a result of the functioning of integrated systems. The study also includes an analysis of modern information technologies, including an analysis of their specifications and capabilities. This will allow us to determine which technologies can be integrated in the synthesis of control systems. Given the importance of protecting data and systems from cyber threats, the study includes an analysis of cybersecurity techniques and technologies that can be applied to integrated systems [2]. To confirm the results of the study, we solved the equation in the state variables of a two-dimensional device, including integration into real control systems and evaluation of their performance.

Research in this area requires an integrated approach and the use of a variety of methods to determine optimal ways to integrate and synthesize control systems using two-dimensional control device and information technology. Which in turn made it possible to measure the effectiveness and reliability of control systems and their ability to adapt to changing conditions [3]. To compare different methods and approaches to integration in information technology, the method of comparative analysis is usually used. Which helps to identify the advantages and disadvantages of different approaches.

The study of the interaction of a two-dimensional control device and information technology for the synthesis of control systems is a multidimensional and multidisciplinary approach that requires the use of a variety of methods and tools.

Results and Findings

To search for equations in the state variables of a two-dimensional control device with a relative degree $\mu_{yy} = 1$, let's consider the equations of state of the object control system [3].

The general form of the state equations in state space for an object with a relative degree $\mu_{yy} = 1$ is as follows:

$$x^{\cdot} = Ax + Bu$$
$$y = Cx + Du$$

where: $x^{\cdot}$ - derivative of the state vector x with respect to time; A - state system matrix; B - input matrix; u - vector of control actions; y - output vector; C - output matrix; D - forward transmission matrix.

For an object control system, where $\mu_{yy} = 1$, it is important that one of the outputs y depends on one of the states $x^{\cdot}$ in accordance with direct transmission D.

Let, for example, we want the state x_1 to influence the output y_1. Then, given that $\mu_{yy} = 1$, we might have the following equation for one of the outputs:

$$y_1 = C_1 x_1 + D_1 u$$

Here: y_1 - one of the exits; x_1 - one of the states; C_1 - corresponding matrix element C in row corresponding y_1 and column corresponding x_1; D_1 - corresponding matrix element D in the row corresponding y_1 and column corresponding to the control action u.

Further, in the state system $x^{\cdot}$, the corresponding equation will depend on this output y_1:

$$x^{\cdot}_1 = A_{11} x_1 + A_{12} x_2 + B_1 u$$

where: A_{11} - A matrix element row, corresponding x_1 and column, corresponding x_1; A_{12} - A matrix element row, corresponding x_1 and column, corresponding x_2, B_1 - B matrix element (row corresponding x_1 and column corresponding to the control action u).

This equation is one of the equations of state of an object control system with a relative degree $\mu_{yy} = 1$, where one of the outputs depends on one based on the state. Let's try to find equations in the state variables of a two-dimensional control device with a relative degree $\mu_{yy} = 1$ at which the object control system.

$$\dot{x} = \begin{bmatrix} 2 & 4 \\ 3 & 6 \end{bmatrix} x + \begin{bmatrix} 1 \\ 1,3 \end{bmatrix} u + \begin{bmatrix} 0,5 \\ 0,3 \end{bmatrix} f, \tag{1}$$

$$y = \begin{bmatrix} 0,5 & 2 \end{bmatrix} x. \tag{2}$$

Equation (1) describes the dynamics of the variable x, where x depends on the previous value, external influence u, and disturbance f.

The factor 2, 4, 3, 6 before x can represent a gain or damping factor, which determines how quickly the variable x responds to changes in its original value x. If this value is large, then the system will be more sensitive to changes in x.

The coefficient 1 and 1.3 before u indicates the influence of external influence u on the variable x. This coefficient may represent the system's sensitivity to influences or its ability to respond to a control signal u.

The coefficient 0.5 and 0.30, before f it is assumed that this is a typo, because such an entry does not correspond to the generally accepted form. There should probably be two different coefficients here: one for f and one for u. So, assuming these are two different coefficients, a coefficient of 0.5 before f may indicate the effect of the disturbance f on the variable x. This coefficient may represent the system's sensitivity to disturbances or its ability to suppress their effects.

Equation (2) defines the variable y as 0.5 and 2, which can mean that the variable y depends linearly on the variable with proportionality coefficients of 0.5 and 2. This can be interpreted as the output variable y, which is a function of the input variable x.

These examples often have second-order astatism to the reference action g and first-order astatism to the disturbance f. In this case, the control time according to the reference influence should be $t_p \leq 1,5c$, and the overregulation should not exceed 10%. Deviation $\varepsilon = g - y$ and the manipulated variable y are measured, but disturbance f and impact g are not measured.

To solve our problem, we will use the analytical method of synthesizing two-dimensional control devices according to the desired indicators

Analyzing (1) and (2), we will find polynomials:

$$B(p) = \beta_m^{-1} B_\Omega(p) = 3,1(p + 0,129),$$
$$A(p) = p^2 - 8p, H(p) = 0,85p + 0,9$$

from the input-output equation of a given object

$$A(p)y(p) = B(p)u(p) + H(p)f(p) \tag{3}$$

In our case, the zeros of the polynomial $A(p)$ are 0 and 8, and the zero of the polynomials $B(p)$ is –0.129, i.e. these polynomials do not have common zeros. Consequently, the given control object is complete and minimally phased. Therefore, it is possible to synthesize a system with matched poles by assuming the characteristic polynomial of a closed-loop system

$D(p)=B_{\Omega}(p)\tilde{D}(p)=(p+0{,}129)\tilde{D}(p)$, where $\tilde{D}(p)$ is a Hurwitz polynomial selected according to the quality conditions of the synthesized system.

In this case, one of the standard transfer functions with a suitable value of the time scale factor can be taken as the desired transfer function of the closed-loop system to the reference action.

In accordance with the above analytical synthesis method, we first look for the input-output equation of a two-dimensional control device of the form

$$R(p)u(p)=Q(p)g(p)-L(p)y(p) \tag{4}$$

where $R(p),Q(p),L(p)$ – polynomials to be determined during the synthesis process. In this case, according to the conditions of physical realizability, the inequalities must be satisfied

$$r-q\geq\mu_{yy}, \qquad r-l\geq\mu_{yy} \tag{5}$$

where $r=\deg R(p), q=\deg Q(p),\ l=\deg L(p), \mu_{vy}$ – index or relative degree of a two-dimensional control device. It depends on the properties of the elements from which the synthesized two-dimensional control is built.

As you can see, the synthesized control device (4) has two inputs: namely, a reference action g and an output $-y$, which is why it is called two-dimensional.

Note that the relative degree μ_{ss} of a controlled dynamic system is the minimum order of the time derivative of the system output, which clearly depends on the control. In the case of a linear two-dimensional control device (4), its relative degree will be equal to:

$$\mu_{yy}=\min\{r-q,r-l\} \tag{6}$$

To solve the synthesis problem, the input-output equation of a closed-loop system is compiled according to (3) and (4)

$$D(p)y(p)=B(p)Q(p)g(p)+H(p)R(p)f(p). \tag{7}$$

Here the characteristic polynomial $D(p)$ is defined by the expression

$$D(p)=A(p)R(p)+B(p)L(p). \tag{8}$$

As is known, to ensure second-order astatism with respect to the reference action, it is necessary that there are two integrators in the open circuit of the system. In our case, there is only one integrator in the object. Therefore, another one is introduced into the two-dimensional control device, for which the polynomial $R(p)$ is taken in the form $R(p)=p\tilde{R}(p)$, where $\tilde{R}(p)$ is an arbitrary polynomial. In this case, according to (7), the condition of first-order astatism with respect to the disturbance f will also be satisfied, since in this equation the image of the disturbance $f(p)$ is multiplied by a polynomial $R(p)$.

As noted above, $D(p)=(p+0{,}129)\tilde{D}(p)$, therefore, substituting expressions for polynomials in (8), we arrive at the equation

$$(p+0{,}129)\tilde{D}(p)=(p^2-8p)p\tilde{R}(p)+3{,}1(p+0{,}129)L(p). \tag{9}$$

In equation (9.9), the binomial $p+0{,}129$ is contained in two products, so it must also be in the third product, that is, it is necessary that $\tilde{R}(p)=(p+0{,}129)\bar{R}(p)$, where $\bar{R}(p)$ is an arbitrary polynomial of degree $r-2$. Next, substituting the resulting expression for $\tilde{R}(p)$ in (9) and reducing the entire equality to a binomial $p+0{,}129$, we will have

$$\tilde{D}(p)=\left(p^2-8p\right)p\bar{R}(p)+3{,}1L(p). \tag{10}$$

The resulting expression is a polynomial equation, which is equivalent to a system of algebraic equations in which the unknowns are $r-2+1$ the coefficients of a polynomial $\vec{R}(p)$ of degree $\vec{r}=r-2$ and r the coefficients of a polynomial $L(p)$ of degree $l=r-1$, according to (5), since by assignment $\mu_{yy}=1$.

The degree $\tilde{\eta}$ of the polynomial $\tilde{D}(p)$ in (10) is obviously equal to the degree of the product $\left(p^2-8p\right)p\bar{R}(p)$, i.e $\tilde{\eta}=r-2+3=r+1$. Consequently, the system of equations to which the polynomial equation (10) is equivalent contains $N_y=\tilde{\eta}+1=r+2$ equations and $N_k=r-1+r=2r-1$ unknown coefficients.

For the said system to be solvable, it is necessary that $N_k=N_y$, i.e. $2r-1=r+2$. From here $r=3$, and using the above formulas we find: $\bar{r}=3-2=1, l=3-1=2, \tilde{\eta}=3+1=4$. In this case, the polynomials: $L(p)=\lambda_2p^2+\lambda_1p+\lambda_0$, $\bar{R}(p)=\rho_1p+\rho_0$, $\tilde{D}(p)=\delta_4p^4+\delta_3p^3+\delta_2p^2+\delta_1p+\delta_0$.

To select the coefficients of the polynomial $\tilde{D}(p)$, as noted above, standard transfer functions are used. In this case, the coefficients of the transfer function corresponding to the fourth-order system are necessary, since $\tilde{\eta}=4$ with second-order astatism and overshoot of no more than 10%. These data are satisfied by the transfer function with standard coefficients: $\Delta_0=1$, $\Delta_1=11{,}8, \Delta_2=16{,}3, \Delta_3=7{,}2, \Delta_4=1$ and $t_{pm}=12c$.

To ensure the required regulation time, the value of the time scale factor is calculated $\omega_0=t_{pu'}/t_p^*=12/3=4$. The desired coefficients of the polynomial $\tilde{D}(p)$ are determined by the formula

$$\delta_i=\Delta_i\omega_0^{n-i} \tag{11}$$

at $n=\tilde{\eta}=4$.

Substituting numerical values gives: $\delta_0=256$; $\delta_1=755{,}2$; $\delta_2=260{,}8$; $\delta_3=28{,}8$; $\delta_4=1$.

Now we can write the system corresponding to equation (10).

Here it looks like

$$\begin{bmatrix} 3{,}1 & 0 & 0 & 0 & 0 \\ 0 & 3{,}1 & 0 & 0 & 0 \\ 0 & 0 & 3{,}1 & -8 & 0 \\ 0 & 0 & 0 & 1 & -8 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \lambda_0 \\ \lambda_1 \\ \lambda_2 \\ \rho_0 \\ \rho_1 \end{bmatrix}=\begin{bmatrix} 256 \\ 755{,}2 \\ 260{,}8 \\ 28{,}8 \\ 1 \end{bmatrix}.$$

The solution to this system: $\rho_1=1$; $\rho_0=36{,}8$; $\lambda_2=179{,}1$, $\lambda_1=243{,}6$, $\lambda_0=82{,}58$ allows us to write polynomials: $R(p)=(p+0{,}129)\left(p^2+36{,}8p\right), L(p)=179{,}1p^2+243{,}6p+82{,}58$.

The product $B(p)Q(p)$, according to equation (7), is the numerator of the transfer function of a closed-loop system for the reference action. On the other hand, the order of astatism according to the driving influence of the synthesized system is equal to 2, this product should be equal to $(\delta_1 p+\delta_0)(p+0{,}129)$. From here the coefficients are found $\chi_0=82{,}58; \chi_1=243{,}6$ polynomial $Q(p)$. As a result, we can write the following equation (4) of the desired two-dimensional control device:

$$\begin{gathered}(p^2+36{,}8p)(p+0{,}129)u(p)=(82{,}58+243{,}6p)g(p)- \\ -(82{,}58+243{,}6p+179{,}1p^2)y(p).\end{gathered} \tag{12}$$

According to the conditions of the problem, the deviation $\varepsilon = g-y$ and the controlled variable y are measured. Therefore, in equation (9.12) g is replaced by the formula $g=\varepsilon+y$. After bringing similar and multiplying polynomials; we get

$$(p^3+36{,}929p^2+4{,}7472p)u(p)=(82{,}58+243{,}6p)\varepsilon(p)-179{,}1p^2y(p). \tag{13}$$

This input-output equation corresponds to the following system of equations in state variables:

$$\dot{z}=\begin{bmatrix}0 & 0 & 0\\ 1 & 0 & -4{,}7472\\ 0 & 1 & -36{,}929\end{bmatrix}z+\begin{bmatrix}82{,}58\\ 243{,}6\\ 0\end{bmatrix}\varepsilon-\begin{bmatrix}0\\ 0\\ 179{,}1\end{bmatrix}y, \tag{14}$$

$$u=\begin{bmatrix}0 & 0 & 1\end{bmatrix}z. \tag{15}$$

The resulting equations describe the two-dimensional control device, the input of which is the deviation ε and the controlled variable y of the object. The relative degree of the found control device is obviously equal to unity.

To check the solution, it is necessary to find, for example, the transfer functions of a closed-loop system. Eliminating deviation ε and control from equations (3) and (13), we find (at zero initial conditions) the following expressions for the transfer functions of the synthesized control system:

$$W_{yg}(p)=\frac{(p+0{,}129)(256+755{,}2p)}{(p^4+28{,}8p^3+260{,}8p^2+755{,}2p+256)(p+0{,}129)},$$

$$W_{yf}(p)=\frac{(p+0{,}129)(0{,}85p^2+32{,}18p+33{,}12)p}{(p^4+28{,}8p^3+260{,}8p^2+755{,}2p+256)(p+0{,}129)}.$$

Based on the results obtained, the following conclusions can be drawn:

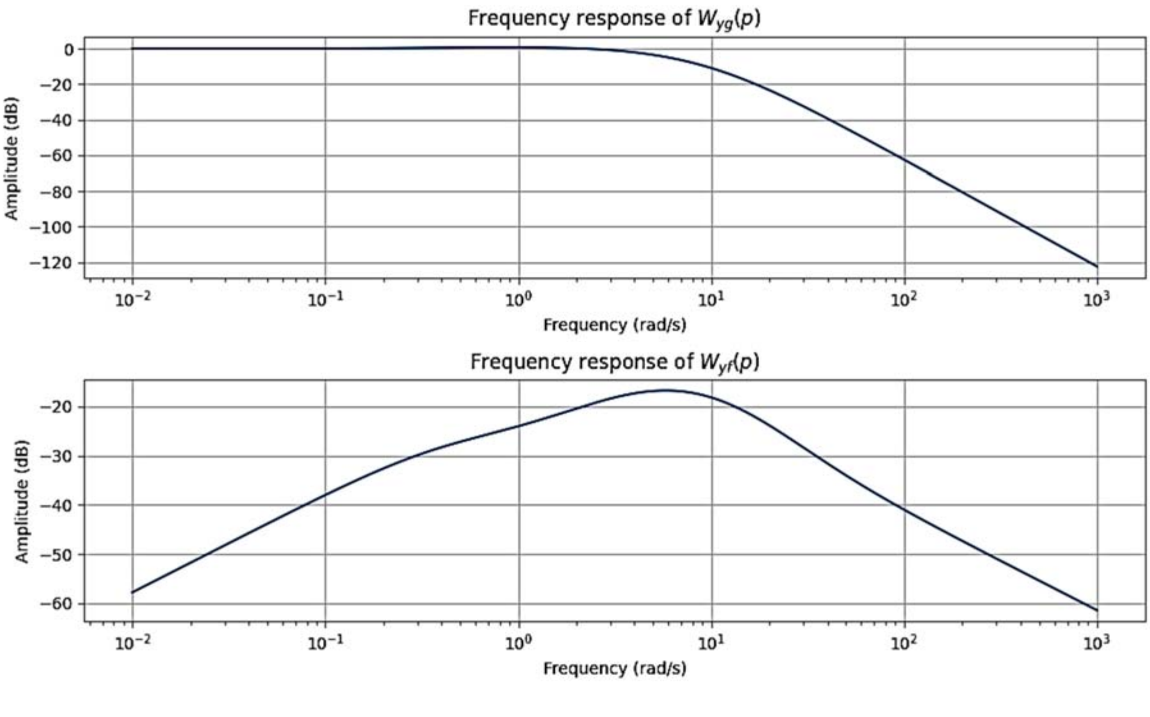
Both transfer functions $W_{yg}(p)$ and $W_{yf}(p)$ depend on the Laplace variable (p) and contain polynomials in both the numerator and denominator. These functions can be used to analyze and model system dynamics as a function of time frequency.

Both functions have a common denominator $(p^4+28{,}8p^3+260{,}8p^2+755{,}2p+256)$ $(p+0{,}129)$, which may indicate the presence of a general dynamic nature in the system.

The functions differ in their numerators: $W_{yg}(p)$ has a numerator $(p+0{,}129)(256+755{,}2p)$ while $W_{yf}(p)$ has a numerator $(p+0{,}129)(0{,}85p^2+32{,}18p+33{,}12)p$. These differences in numerators may indicate different aspects of the system or different input signals that are being considered.

Analyzing these transfer functions can help understand how the system reacts to external influences and what dynamic characteristics it has. Solutions to the system of equations associated with the transfer functions can provide information about stability, response to different frequencies, and other important properties of the system [4, p. 104]. The constructed transient functions of the closed-loop system (1), (2), (14), (15), corresponding to the obtained transfer functions and simulation results, it follows that the synthesized system satisfies the requirements for the transient process for the master action, as well as the requirements for the accuracy of the master influencing g and suppressing the influence of disturbance f.

The graphs in figure show the change in the amplitude of the transfer functions depending on the frequency. We see that both functions have different amplitude response profiles, which may indicate different dynamic properties of the system [5]. Dips and peaks are detected in the graphs, which may indicate the presence of resonances or frequency resonances in the system. These features may affect the dynamics of the system and require additional analysis. The graphs show no signs of system instability, which is a positive aspect. However, for a more accurate assessment of the stability of the system, additional analysis is necessary, for example, analysis of the roots of the characteristic polynomial. Amplitude characteristics allow us to evaluate how the system reacts to external disturbances. Differences in amplitudes may indicate different sensitivity of the system to different input signals.



The graphs of change in the amplitude of the transfer functions depending on the frequency

To effectively integrate a two-dimensional control device, it is necessary to develop methods and technologies that will allow interaction with them through modern information platforms. This includes the creation of specialized software interfaces, the development of algorithms for processing data from control devices and ensuring compatibility between physical devices and information systems [6].

Another aspect of the problem is related to ensuring security and data protection when integrating physical control devices with information technology. This includes protecting against unauthorized access to control devices, ensuring the confidentiality of information transferred between devices and information systems, and ensuring the integrity of data during transmission and processing. The problem of integrating a two-dimensional control device into information technology for the synthesis of systems requires the development of integrated approaches and innovative solutions that will allow the effective use of physical devices in modern information systems.

Conclusion

According to the simulation results, transient processes in the system in response to the command signal g correspond to pre-established requirements. This means that the system quickly and stably responds to changes in the input signal and achieves the specified goals within the specified time frame [1-4]. The accuracy of the master action in the synthesized system ensures high accuracy when working out the master influence. This is important, especially in the context of control systems where accuracy and reliability are key. The simulation results also indicate the system's ability to effectively drive the disturbance signal f. This means that the system is stable and able to cope with external influences or disturbances, minimizing their impact on the output.

Synthesis of a control system that includes a two-dimensional control device requires an integrated approach that combines both hardware and software components, and information technology plays a key role in the optimization and automation of control systems. The integration of 2D control into information technology opens up new prospects for creating more efficient and adaptive control systems, which is of great importance in today's world where automation and optimization play an important role in improving the productivity and quality of various processes. The obtained results confirm that the synthesized system has desirable properties in terms of accuracy and stability, making it suitable for specific applications and requirements related to driving inputs and disturbance suppression.

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