Generalized integro - differentiating controller for mechatronic devices of mobility nodes of humanoid robots

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Abstract

The article considers the generalized integro-differentiating controller (GID-controller) as an alternative to the PID-controller for use in cascaded SISO LTI systems for automatic control of mechatronic devices of mobility nodes of humanoid robots. GID - controller is set by a generalized integro-differentiating circuit or a connection of an ideal integrator with generalized prejudice-delay compensators. The article shows that the main positive property of the GID controller compared to the PID controller is that, in the presence of the SISO LTI mathematical model of the control object, the primary parametric setting of the GID controller gives a practically acceptable rational result of controlling the robot movements. That is, the initial parametric setting of the GID controller does not require further additional adjustment of the controller parameters. This positive quality of the GID - controller allows you to significantly reduce the time for adjusting the controller parameters on a real object. Therefore, the method of parametric adjustment of the GID - controller was called the method of express adjustment of the generalized integro-differentiating controller (MEA GID - controller). The result of a computer experiment is presented, which showed that the MEA GID - controller provides quality, simplicity, convenience and time saving during parametric adjustment of the controller, which justifies the expediency of using the GID – controller for controlling mechatronic devices of robot mobility nodes in general and, in particular, humanoid robots with increased requirements to human-like movements.

Keywords

Automatic control system, PID-controller, integro-differentiating circuit, prejudice-delay compensators

1. Introduction

When making humanoid robots designed to work next to human (housework, nursing robots, service jobs in customer service areas), one of the main requirements is the implementation of the principle of safe interaction between humanoid robots and human [1-6]. This principle is implemented thanks to an approach that can be called "smoothness + sensuality" ("S + S"): the robots perform movements that resemble (practically do not differ from) human movements, that means, that they are smooth and sensual in terms of strength [5-7]. The structure of cascade (multi-loop) SISO LTI automatic control systems with the properties of quasi-invariance (quasi-adaptability) to the action of external disturbances in the best way ensures the implementation of the "S + S" approach [8-11] (see Figure 1). Usually, in each of the cascades, controller with parametric adjustment are used with a structure of PID-controller varieties (from a proportional controller to a full structure with proportional, integral, and differential signals) [12, 13]. The presence of an integrating link provides the property of quasi-invariance to external disturbances such as step action [8]. Considering the fact that in humanoid robots the number of mobility nodes exceeds hundreds [6, 7, 9], and in cascade automatic control systems of drives in mobility nodes, at least two cascades are used, the total number of controllers that need to be adjusted can exceed thousands. It is clear that an urgent engineering problem arises regarding the rapid adjustment (or

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re-adjustment) of controllers. Let us emphasize that, if computer numerical tuning programs are used for parametric tuning according to algorithmically set criteria, then the actual task of quick adjustment of the controller turns into the actual task of finding the first successful approximation, that is, finding the initial conditions from which the computer adjustment algorithms "starts" [14–17].

2. Problem Statement

Two-cascade control systems (Figure 1) have better indicators of control quality compared to single-cascade systems [8]. Therefore, they should be used where they do not exist yet. If two-cascade control is abandoned in those mobility nodes, where it exists, in order to reduce the number of controllers to be adjusted, the following positive properties of cascade control will be lost:

1. External disturbances acting on the part of the control object that is covered by local feedback will directly affect the output coordinate, and won`t be reduced in the internal auxiliary loop.
2. Parametric disturbances that occur in the internal circuit will significantly affect the output signal.
3. The time of the transient response at the output of the system will increase significantly if the internal feedback is turned off, due to which the dynamic properties of the mechatronic devices of the mobility node are corrected.

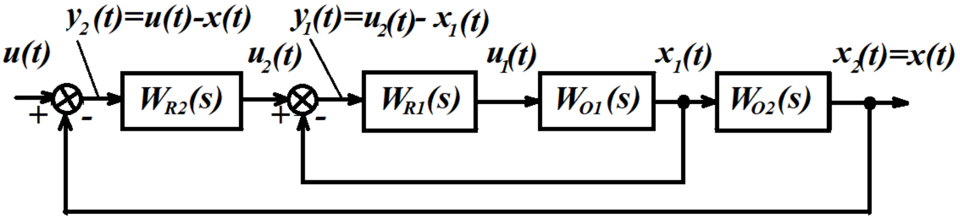

Figure 1: Structural diagram of the cascade (multi-circuit) SISO LTI system of automatic control of mechatronic devices in the mobility nodes of humanoid robots: $W_{Rj}(s), W_{Oj}(s)$ $(j = 1,2)$ - scalar continuous transfer functions that reflect the algorithm of the controller (index *Rj*) and mathematical model of the control object (index Oj) corresponding to the first cascade (internal circuit, j=1) and the second cascade (external circuit, j=2) of the automatic control system

Currently, in mechatronic devices of mobility nodes of humanoid robots are used (almost 100%) as controllers in both cascades PID-controllers [8-12]. As known, the PID-controller forms its output signal as the sum of proportional, integral and differential signals from the error applied to its input. We will use the so-called standard form to display the mathematical model of the PID-controller operation algorithm

$$W_{PIDj}(s) = k_{pj} \cdot \left(1 + \frac{1}{T_{ij} \cdot s} + \frac{T_{dj} \cdot s}{\tau_{dj} \cdot s + 1}\right), \tag{1}$$

where (according to recommendations [8]) we assume that the additional time constant can be calculated from the following relation $\tau_{dj} = 0.15 \cdot T_{dj}$ $(j = 1,2)$.

Let us assume that the mathematical model of the control object is known $W_{Oj}(s)$ $(j = 1,2)$. As a controller in both cascades, it is planned to use a PID controller, that is, the structure of the controller is known: $W_{Rj}(s) = W_{PIDj}(s)$ $(j = 1,2)$. As a rule, a two-stage procedure is used to set the parameters of both PID controllers, in which the smoothness (human-likeness) of movements is implemented in the automatic control system: at the first stage, the initial adjustment is performed using the Ziegler-Nichols or Cohen-Kun methods; at the second stage, the result of the initial adjustment is improved using computer simulation. The duration and effectiveness of the second stage significantly depends on the initial adjustment. The experience of adjusting the PID - controller as a whole, shows that 90% of the time (and at the same time not always with the desired result) is spent on the second stage of adjustment [8-12].

A scientific-technical problem arises: to reduce the time spent on such a setting of the cascade system of automatic control of mechatronic devices in mobility nodes, which ensures the smoothness of the movements of the humanoid robot, that means that almost human-like movements are achieved.

The engineering experience of solving the problems of adjusting the structure and parameters of the controllers indicates two effective approaches: first, to ensure a successful first approximation to the acceptable structure and parameters of the controller (initial adjustment); secondly, after the first approximation, adjust the minimum number of parameters.

3. Method of express adjustment of the generalized integro-differentiating controller (MEA GID- controller)

The initial data for solving the scientific-technical problem is: the structure of the cascaded SISO LTI automatic control system (ACS) (Figure 1) and the mathematical model of the control object $W_{Oj}(s)$ $(j = 1{,}2)$.

An ACS with PID controllers is considered as a prototype ACS, which should be improved by usage of a GID - controller. PID - controllers are connected to the internal and external cascades respectively (Figure 1).

The task of synthesizing a cascade ACS (Figure 1) is considered solved if the algorithms of the controllers' operation are synthesized in the form of their transfer functions $W_{Rj}(s)$ $(j = 1{,}2)$.

The general approach to the synthesis of transfer functions of regulators $W_{Rj}(s)$ $(j = 1{,}2)$ is as follows. First, the regulator for the internal cascade (circuit) is synthesized with the mathematical model of its operation algorithm, which is specified by the transfer function $W_{R1}(s)$, where as a mathematical model of the control object is considered $W_{O1}(s)$ (Figure1). After that, the synthesis of the regulator of the external cascade (circuit) is performed, which means that the transfer function is found $W_{R2}(s)$. As a mathematical model of the control object, the serial connection of the transfer functions of the internal cascade (circuit) and $W_{O2}(s)$.

In order to solve the scientific-technical problem set above, it is proposed: replace the PID-controllers in the cascade system-prototype with generalized integro-differentiating controllers (GID - controllers), for the initial adjustment of which use a special method of initial express adjustment with increased adjustment quality.

Content of the main material: structure and parameters of GID - controller; method of express adjustment of GID - controller; an example of the initial setting of PID and GID - controllers for a cascade ACS and comparative modeling of transient response in a cascade ACS with synthesized regulators.

Structure and parameters of GID - controllers.

As an alternative to the PID-controller algorithm, it is proposed to apply the algorithm, which is given by the transfer function of the GID-controller:

$$W_{UID}(s) = \frac{k_{GID}}{s^{v}} \cdot \frac{(T_1 s + 1)^{m_1} \cdot (T_3 s + 1)^{m_3}}{(T_2 s + 1)^{m_2} \cdot (T_4 s + 1)^{m_4}} \qquad (2)$$

parametric synthesis of which (search of parameters $k_{UID} > 0; v, m_{1,2,3,4} \in \{0; 1; 2; \dots\}$; $T_{1,2,3,4} > 0$) is proposed to be carried out by the method of express adjustment of the GID - controller (MEA GID-controller). We emphasize once again that the MEA GID-controller is considered as a method of primary parametric adjustment of the regulator.

We will remind, that according to the terminology used in the national or English-language scientific literature, the GID - controller is also called a generalized integro-differentiating circuit or a connection of an ideal integrator with generalized prejudice-delay compensators.

3.1. Stages of MEA GID-controller

Stage 1. Create a mathematical model of an open circuit.

Consider the open circuit in the form of a serial connection of mathematical models of the GID - controller and control object and calculate the transfer function of the open circuit:

$$W_d(s) = W_{GID}(s) \cdot W_o(s) = k_{GID} \cdot \frac{(T_1 s+1)^{m_1} \cdot (T_3 s+1)^{m_3}}{(T_2 s+1)^{m_2} \cdot (T_4 s+1)^{m_4}} \cdot \frac{1}{s^v} W_o(s) = W^*_{GID}(s) \cdot W^*_o(s), \quad (3)$$

where

$$W^*_{UID}(s) = k_{GID} \cdot \frac{(T_1 s+1)^{m_1} \cdot (T_3 s+1)^{m_3}}{(T_2 s+1)^{m_2} \cdot (T_4 s+1)^{m_4}};$$

$$W^*_o(s) = \frac{1}{s^v} W_o(s)\ ;$$

$$W_o(s) \ = \frac{1}{s^l} \cdot \frac{b_m s^m + b_{m-1} s^{m-1} + \cdots + b_1 s + b_0}{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0},$$

W_o– transfer function of the control object. We will remind that considered as known: l – the number of ideal integrators in the mathematical model of control object; m and n - orders of polynomials in the numerator and denominator $W_o(s)$ and the coefficients of these polynomials in the corresponding powers s.

Stage 2. Set the structural parameters of the transfer function $W_{GID}(s)$ of GID-controller v and $m_{1,2,3,4}$.

Usually, v and $m_{1,2,3,4} \in \{0; 1; 2\}$.

We choose v (v – the number of ideal integrators in the controller) to fulfill the requirement to ensure the given order of astatism of the closed circuit (Figure 1) taking into account the number of ideal integrators in the control object.

We choose $m_{1,2,3,4}$ taking into account the properties of prejudice-delay compensators (PDC)

$$W_{12}(s) = \frac{T_1 s+1}{T_2 s+1} \text{ and } W_{34}(s) = \frac{T_3 s+1}{T_4 s+1}\ .$$

Analysis of the amplitude and phase-frequency characteristics of bias-delay compensators allows us to draw the following conclusions:

1. A PDC with the properties of an advance link allows you to increase the phase margin.
2. A PDC with the properties of a delay link allows you to reduce the impact of high-frequency disturbances.
3. The sequential inclusion of the prejudice-delay links with raising the binomials to the appropriate power $m_{1,2,3,4}$ allows you to obtain and strengthen both positive effects.

Stage 3. Calculate the cutoff frequency ω_z for the transfer function $W^*_o(s)$, that means, the frequency at which $|W^*_o(j \cdot \omega_z)| = 1$.

For designing the transfer function

$$W^*_o(s) = \frac{1}{s^{v+l}} \cdot \frac{b_m s^m + b_{m-1} s^{m-1} + \cdots + b_1 s + b_0}{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0} \quad (4)$$

and calculating the cutoff frequency, corresponding functions of the computer mathematics system MATLAB+Simulink can be used.

Stage 4. Calculation of the GID-controller parameters.

Based on the known cut-off frequency $\boldsymbol{\omega_z}$, calculate the parameters of the transfer function of the GID-controller:

$$T_1 = \frac{3.3}{\omega_z};\ T_3 = \frac{1}{3.3 \cdot \omega_z};\ T_2 = \frac{1}{33 \cdot \omega_z};\ T_4 = \frac{1}{330 \cdot \omega_z}\ .$$

Written down ratios make it possible to obtain a successful first approximation to the acceptable values of the GID-controller parameters at any values of its structural parameters $\boldsymbol{v}$ and $\boldsymbol{m_{1,2,3,4}}$. These ratios are obtained as a result of empirical generalization of the experience of synthesis of GID - controllers.

Stage 5. Selection of structural parameters$m_{1,2,3,4}$ and the gain of the regulator k_{GID}.

First step: set $m_{1,2,3,4} = 1$.

Design a computer mathematical model and perform a simulation experiment for selection k_{GID} . Recommended: Start with a value $k_{GID} \in [0.1 \cdot k_{pKZ-N}; 0.5 \cdot k_{pKZ-N}]$, where k_{pKZ-N} – gain coefficient, which is calculated by the method of Ziegler-Nichols oscillations [8], and choose such a value of k_{GID}, at which the duration of the transient response, oscillation and overregulation will have acceptable values for the specific task.

If it was successful in choose k_{GID}, in which the above stated parameters of the transient response satisfy the requirements of a specific task, then we consider that stage 5 is completed.

If it was not possible to meet the requirements of a specific task, then we change one of the structural parameters $m_{1,2,3,4}$ and repeat the selection k_{GID}.

During the initial setup, stage 5 is performed in the interactive "manual" mode. Experience shows that no more than a few "runs" of a computer mathematical model are enough to obtain a result acceptable for practical use, that is, before stopping the adjustment as a whole. Let us emphasize that the "human-likeness" of movements is assessed by experts, although formally the smoothness of movements can be specified using well-known standard forms [12].

4. Results and discussions

In this section, we will consider an example of the initial setting of the PID- and GID-controllers for a cascade ACS (Figure 1) and perform a comparative simulation of transient responses in a cascade ACS with synthesized controllers. Let us start with the initial setting of the PID - controllers for the cascade ACS (Figure 1).

The initial setting of the PID - controllers for the cascade ACS (Figure 1). For the initial setting of the PID-controller parameters (that is, determination of the gain k_p, constant of integration T_i and constant of differentiation T_d) we will use well-known methods [8]: Ziegler-Nichols oscillations (KZ-N); Ziegler - Nichols when using the transient response (Z-NPP); Cohen – Kuhn using the transient response (K-KPP). To demonstrate the exact method by which the parameters of the PID controller were determined, we will use the corresponding indices for each of the methods: k_{pKZ-N} ,T_{iKZ-N} ,T_{dKZ-N} ; k_{pZ-NPP} ,T_{iZ-NPP} ,T_{dZ-NPP}; k_{pK-KPP} ,T_{iK-KPP} ,T_{dK-KPP} .

The above-mentioned methods require conducting a computer or field experiments [8-12]. According to the results of the experiment, auxiliary parameters are determined, which we will denote as $K_0, P_0; x_0(t_0), x_{0\infty} = \lim_{t\to\infty} x_0(t), t_0, t_1, t_2$. Physical and mathematical content of these parameters is illustrated with the help of figures 2 and 3.

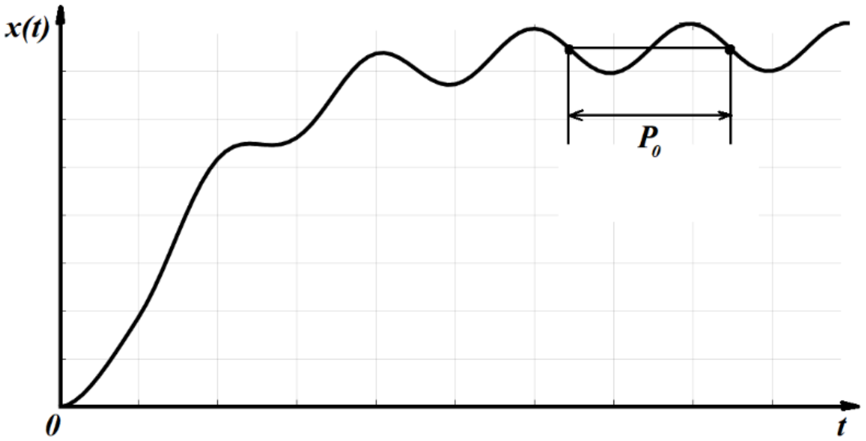

Figure 2: A transient response with constant oscillations with a period of P_0 at the output of a closed system consisting of a proportional controller with a gain factor of K_0 and a control object: the values K_0, P_0 are used to calculate the parameters (initial setting) of the PID - controller using the Ziegler-Nichols oscillation method

According to the known $K_0, P_0\ and\ x_0(t_0), x_{0\infty} = \lim_{t\to\infty} x_0(t), t_0, t_1, t_2$ parameters of the PID-controller are calculated using the above-mentioned methods [8]:

$$k_{pKZ-N} = 0.6 \cdot K_0\ , T_{iKZ-N} = 0.5 \cdot P_0\ , T_{dKZ-N} = \frac{P_0.}{8};$$

$$k_{pZ-NPP} = 1.2 \cdot \frac{D_2}{D_0 \cdot D_1}\ , T_{iZ-NPP} = 2 \cdot D_1\ , T_{dZ-NPP} = 0.5 \cdot D_1;$$

$$k_{pK-KPP} = \frac{D_2}{D_0 \cdot D_1} \cdot \left(0.9 + \frac{D_1}{12 \cdot D_2}\right),$$

$$T_{iK-KPP} = D_1 \cdot \frac{30 \cdot D_2 + 3 \cdot D_1}{9 \cdot D_2 + 20 \cdot D_1},$$

$$T_{dK-KPP} = \frac{4 \cdot D_1 \cdot D_2}{11 \cdot D_2 + 0.2 \cdot D_1},$$

where $D_0 = x_{0\infty} - x_0(t_0), D_1 = t_1 - t_0, D_2 = t_2 - t_1$.

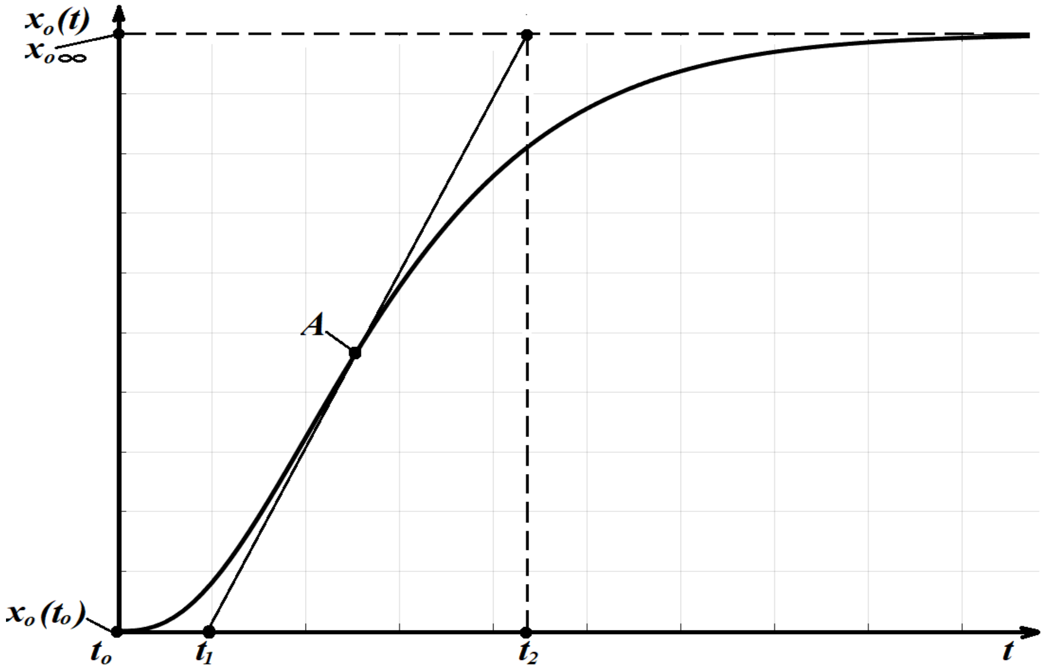

Figure 3: Transient response at the output of the control object: value $x_0(t_0), x_{0\infty} = \lim_{t\to\infty} x_0(t), t_0, t_1, t_2$ are used to calculate parameters (initial setting) of the PID - controller by methods of Ziegler-Nichols and Cohen – Kuhn when using a transient response (a tangent is drawn at point A (the inflection point of the transient response))

We consider that the mathematical model of the mechatronic device in each of the mobility nodes is given by the continuous transfer functions $W_{o1}(s)$ and $W_{o2}(s)$ (Figure 1). The transfer function $W_{o1}(s)$ can be calculated as the transfer function of serially connected links of directed action. These links are a power transformator with a transfer function $W_f(s)$ and a direct current motor (DC) with a transfer function $W_{DPS}(s)$, where the output signal is considered to be the angular speed of the rotor, i.e.:

$$W_{o1}(s) = W_f(s) \cdot W_{DPS}(s).$$

The first cascade (circuit) consists of a controller with a transfer function $W_{R1}(s)$ and a control object with a transfer function $W_{o1}(s)$ (Figure 1). The second cascade consists of a controller with a transfer function $W_{R2}(s)$ and a control object with a transfer function equal to the product of the transfer functions of the first cascade (circuit), $H_1(s) = \frac{W_{R1}(s) \cdot W_{o1}(s)}{1 + W_{R1}(s) \cdot W_{o1}(s)}$ to the transfer function $W_{o2}(s) = \frac{1}{s}$, where the output signal is the rotation angle of the DC motor rotor.

When performing computer experiments, typical transfer functions of mechatronic devices of mobility nodes of humanoid robots were used [8-12]:

$$W_f(s) = \frac{10}{0.0003 \cdot s^2 + 0.04 \cdot s + 1} ; W_{DPS}(s) = \frac{1}{0.4 \cdot s^2 + 1.3 \cdot s + 1} .$$

Let us perform the initial setting of the PID - controller of the first cascade using the above stated methods. During the initial setting of the PID - controller of the first cascade (internal circuit), the following auxiliary values of parameters were obtained:

$$K_0 = 3.5, P_0 = 0.72\ s;\ x_0(t_0) = 0, x_{0\infty} = 10,\ t_0 = 0\ s,\ t_1 = 0.25\ c,\ t_2 = 2\ s\ .$$

The result of calculating the parameters of PID - controller of the first cascade (internal circuit):

$$k_{pKZ-N1} = 2.100\ , T_{iKZ-N1} = 0.3600\ s\ , T_{dKZ-N1} = 0.0900\ s;$$

$$k_{pZ-NPP1} = 0.8400\ , T_{iZ-NPP1} = 0.500\ s\ , T_{dZ-NPP1} = 0.1250\ s;$$

$$k_{pK-KPP1} = 0.6383\ , T_{iK-KPP1} = 0.6416\ s,\ T_{dK-KPP1} = 0.0907\ s.$$

Let us perform the initial setting of the GID - controller of the first cascade using the MEN UID - regulator. Assume that v and $m_{1,2,3,4}$ are equal to one. We will calculate the cut-off frequency and parameters of the GID - regulator of the first cascade (internal circuit). We will use the positioning of the MEA GID-controller and as a result we will get:

$$\omega_{z1} = 2.61\ \frac{rad}{s}\ , T_{11} = 1.2644\ s,\ T_{31} = 0.1161\ s, T_{21} = 0.0116\ s,$$

$T_{41} = 0.0012\ s$. We assume, that $k_{UID1} = 0.1 \cdot k_{pKZ-N1}$=0.21 .

Before moving on to adjusting the parameters of the controller of the second cascade (Figure 1), consider the transient response at the output of the two-cascade ACS under the condition that $W_{R2}(s) = 1$. Let us clarify the issue of the necessity to complicate the general procedure for setting up a two-stage ACS by adjusting the controller for the second cascade.

Let us perform a visual analysis of the transient responses (see Figure 4) at the output of the two-stage ACS (Figure 1).

This analysis shows: when using the GID-controller, the initial setting of which is performed using the proposed method, the smoothness of movements in the mobility node of the humanoid robot will be better than when using the PID-controller.

Thus, if there is no need to reduce the readjustment and the duration of the transient response, then it can be assumed that the cascade ACS can be designed with the connection of only one GID-controller in the internal cascade of the ACS (we consider the external cascade as having a proportional controller with a gain factor connected to it, which is equal to one).

We especially emphasize that it is not necessary to adjust the GID - controller: only the initial setting is enough.

Let us assume that there is still a necessity to reduce the duration of the transient response while maintaining the smoothness of the movements in the mobility node. Then we will perform the initial setting of the PID and GID-controllers for the second cascade (circuit). Since $W_{O2}(s) = \frac{1}{s}$, then only the Ziegler-Nichols oscillation method can be used to adjust PID-controller.

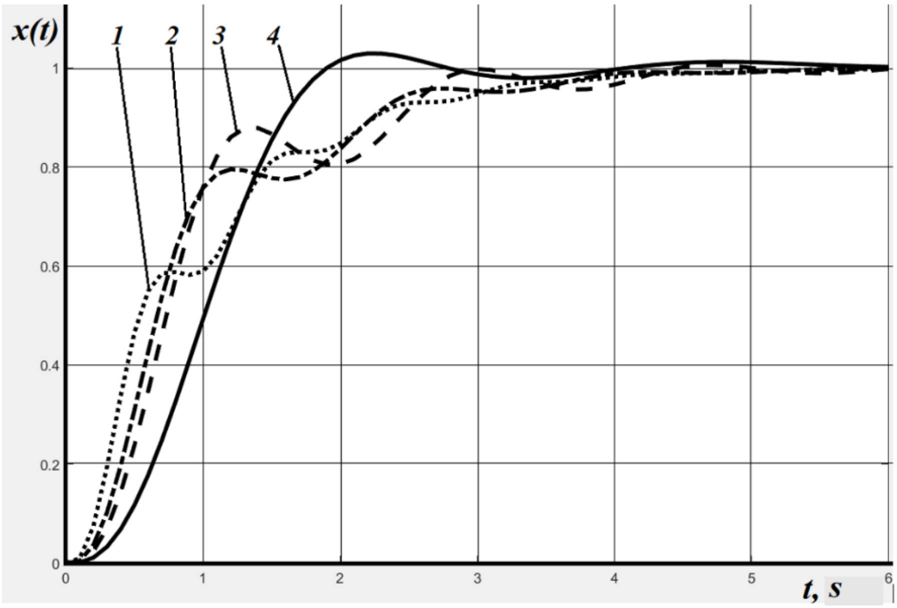

Figure 4. Transient response at the output of the two-cascade ACS (Figure 1) under the condition that $W_{R2}(s) = 1$ and different $W_{R1}(s)$: 1, 2, 3, – transfer function $W_{R1}(s)$ is equal to the transfer function of the PID - controller, the parameters of which are adjusted by the methods of Ziegler-Nichols oscillations, Ziegler-Nichols when using a transient response, and Cohen-Kuhn when using a transient response respectively; 4 - transfer function $W_{R1}(s)$ is equal to the transfer function of the GID - controller.

During the initial setting of the PID - controller of the second cascade (external circuit), the following auxiliary values of parameter were obtained

$$K_0 = 3.5, P_0 = 0.72\ s\ .$$

Based on these values, the parameters of the PID-controller of the second cascade were calculated:

$$k_{pKZ-N2} = 1.800\ , T_{iKZ-N2} = 0.3300\ s\ , T_{dKZ-N2} = 0.0825\ s.$$

Let us move on to setting up the GID-controller. Assume, that v and $m_{1,2,3,4}$ equal to one. During the initial setting of the GID-controller of the second cascade (external circuit), the following value of the cutoff frequency was obtained $\omega_{z2} = 0.99\ \frac{rad}{s}$ and the values of the GID-controller were calculated:

$$T_{12} = 3.3333\ s,\ T_{32} = 0.3061\ s,\ T_{22} = 0.0306\ s,\quad T_{42} = 0.0031\ s\ .$$

Let us assume, that $k_{UID2} = 0.2 \cdot k_{pKZ-N2}$=0.36 . As we can see (see Figure 5), the use in the second cascade of the GID-controller with the initial setting of parameters allows to obtain smoother movements in the mobility node of the humanoid robot compared to the use of the initially configured PID-controller. We note, that there will be almost no readjustment. In order to improve the result of the GID-controllers application, we will change the structural parameters of the GID-regulators in both cascades (circuits). Let us assume, that $v = 1$ and $m_{1,2} = 1, m_{3,4} = 2$ provided that the parameter values $T_{1j},\ T_{3j},\ T_{2j},\ T_{4j}\ (j = 1,2)$ and k_{UID1} remained unchanged. Let us assume, that $k_{UID2} = 0.5 \cdot k_{pKZ-N2}$. It was possible to reduce the duration of the transient response by almost two times while maintaining the smoothness of the movement and the absence of readjustment (Figure 6).

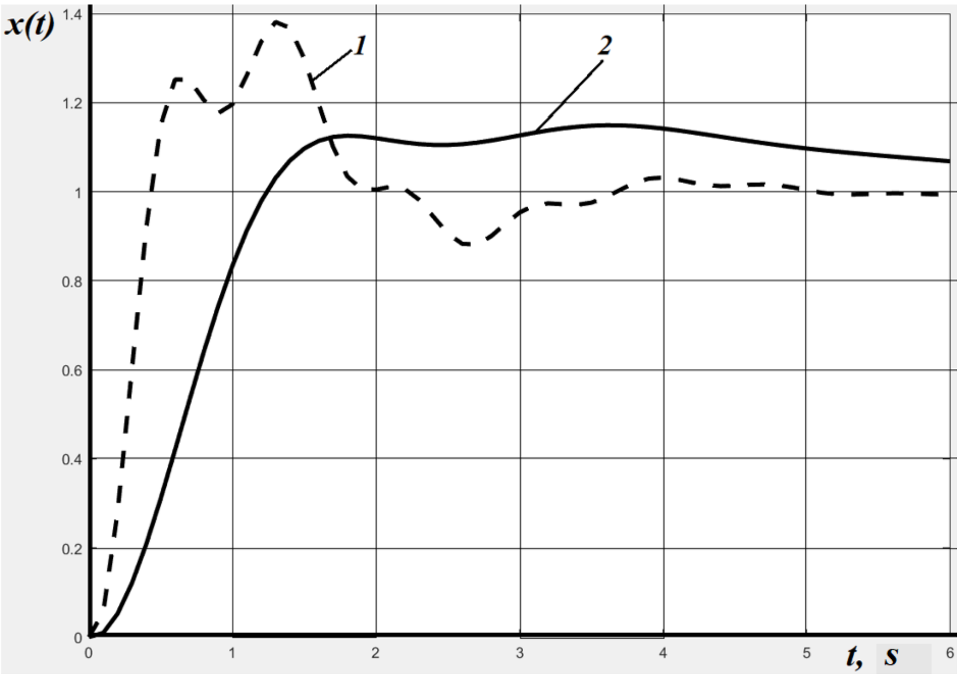

Figure 5. Transient responses at the output of the two-cascade ACS (Figure 1) under the condition that: 1 – transfer functions $W_{R1}(s)$and $W_{R2}(s)$are equal to the transfer functions of the PID - controllers, parameters of which are adjusted by the Ziegler - Nichols oscillation method; 2 – transfer functions $W_{R1}(s)$ and $W_{R2}(s)$ are equal to the transfer functions of the GID - controllers, under the condition that the structural parameters of the GID - controllers v and $m_{1,2,3,4}$are equal to one

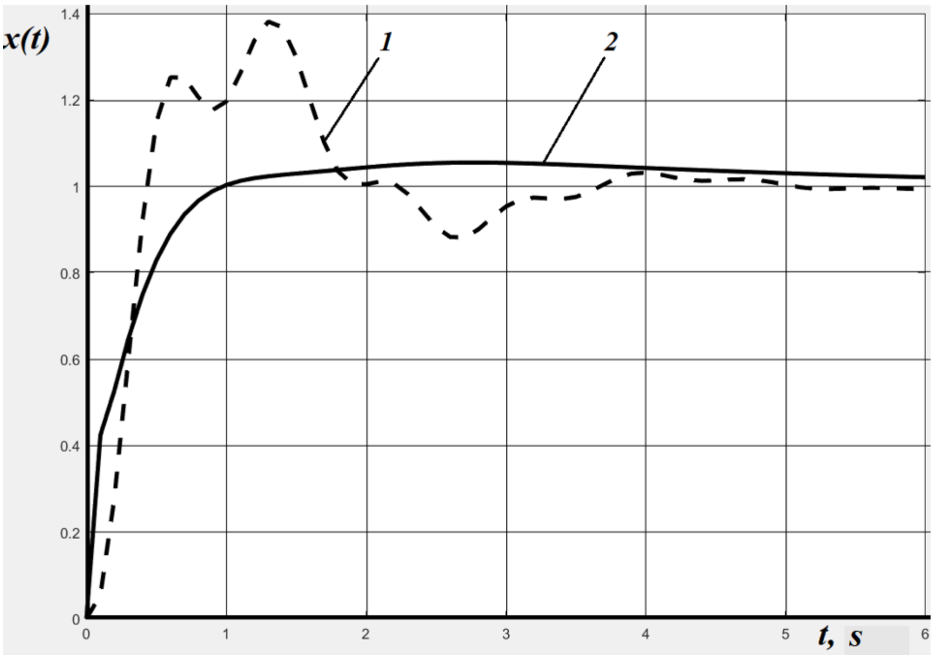

Figure 6. Transient responses at the output of the two-cascade ACS (Figure 1) under the condition that: 1 – transfer functions $W_{R1}(s)$ and $W_{R2}(s)$ are equal to the transfer functions of the PID - controllers, parameters of which are adjusted by the Ziegler - Nichols oscillation method; 2 – the transfer functions $W_{R1}(s)$ and $W_{R2}(s)$ are equal to the transfer functions of the GID - controllers, under the condition that the structural parameters of the GID - controllers v v and $m_{1,2,3,4}$ are equal to one, and $m_{3,4} = 2$

5. Conclusions

As an alternative to the PID-controller for usage in cascaded SISO LTI systems for automatic control of the mobility nodes of humanoid robots, it is proposed to use a controller, which is set by a generalized integro-differentiating circuit or a connection of an ideal integrator with generalized prejudice-delay compensators. This controller was called a generalized integro-differentiating controller (GID - controller).

The main positive property of the GID-controller compared to the PID -controller is that when SISO LTI mathematical model of the control object is available, the primary parametric setting of the GID-controller gives an almost acceptable rational result of control that does not require additional adjustment. Therefore, the method of parametric adjustment of the GID - controller was named the method of express adjustment of the generalized integro-differentiating regulator (MEA GID-controller).

MEA GID-controller provides quality, simplicity, convenience and time saving during parametric adjustment of the controller, which justifies the expediency of using the GID - controller for controlling mechatronic devices of robot mobility nodes in general and, in particular, humanoid robots with increased requirements for human-like movements.

The computer experiment presented in the article illustrated and confirmed the positive properties of the GID - controller, which give it an advantage compared to the PID - controller.

Further research will be aimed at developing a method of structural-parametric synthesis of the GID - controller and its application in automatic control systems with significant nonlinearities.

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