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Development of algorithms of industrial robot training systems

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1. Introduction

Robotic systems create fundamentally new opportunities to liberate people from many kinds of heavy, monotonous labor, including in unhealthy and dangerous areas.

In the development and implementation on the production of robotic systems becomes actual question of industrial robot programming by the method of training, as well as their rapid retraining, for example, in conditions of work in a flexible production system. This is one of the important prerequisites for the successful introduction of robots and achievement of high labor productivity.

The effectiveness of the human-robot system depends not only on speed and accuracy characteristics of industrial robot executive body, but also on the characteristics of its control device [1, 2].

In command mode - the human operator produces the training of industrial robot with remote control, turning on or off separately the drives for each link of the robot executive body by pressing the appropriate buttons, or toggle switches [2, 3]. In this method the accuracy of the positioning of the executive body can be quite high, but its moving speed remains low throughout the training [4].

In the copying system the master device is performed geometrically similar to the executive body [5, 6]. At that, each link of executive body copies the motion of the appropriate link of master device. Such systems are simple in management, however, have several disadvantages: firstly, the complicated construction of the master device, secondly, it is practically impossible manipulator control which differs in the kinematics from the master device, and thirdly, the operator must perform such motions that replicate the executive body in the performance of an operation. This leads to operator fatigue. Furthermore, the coefficient of the system transfer is constant and relatively high, this does not provide a high positioning accuracy.

In the work developed more simple by construction the master devices of the copying manipulators [7], in which the links of executive body replaced by one elastic element. On it are placed position sensors. In such systems the output point of the executive body practically copies a motion of the output point of master device. They eliminate many the disadvantages of the master device of the copying manipulators. But the accuracy of control still remains low.

In semi-automatic systems of training the multi-stage control handles are used as the master devices [1, 2]. The kinematics of control handles can be arbitrary, not like the kinematics of the executive body. In each mobility degree of the master device are placed the position sensors, the signals from these are served to the computing device, which forms the control signals. Here are possible the various control algorithms. Control handles have relatively small sizes and are designed for small motions of the human hand, but are require certain skills from the operator during operation. In addition, the operator is forced to perform the transport operations and the requiring accuracy operations at one and the same values of the system parameters. At the same time the requirements for these operations are diametrically opposed, which results in the situation when considered types of systems do not provide optimal quality of the fulfillment of the first and second kinds of the manipulation operations.

The most well known way out of the situation in semi-automated systems is the use of combined control systems, in particular, position-speed control systems [1], but they have some disadvantages. Firstly, a number of similar systems at sequential switching from the positional mode in speed mode, and then again in positional mode, do not retain certain value of system transfer coefficient. In this case, in each new operating mode for some time the operator has to adapt to the new state of the system, which results in operation deterioration of the system of semi-automatic training. Secondly, it should be especially noted the complexity of these systems, because they relate to the class of multicoordinate systems with variable structure.

The monograph presents research methods of manipulators dynamics on the basis of closed kinematic chains and control systems watching drives with the coordinate-parametric regulation. The imitation modeling on MATLAB (Simulink) for different input actions of the control system dynamics watching drives of the manipulator with the coordinate-parametric regulation is conducted [8].

2. Development of the algorithms of coordinate-parametric control

Obtaining coordinate-parametric control algorithms of training manipulator robots is based on the use of the mnemonic control concept [1]. This concept as applied to robotics devices should characterize the qualities of manual control, which provide coordination in the management process of the geometric properties of the two working spaces - the operator's hands and the capture of manipulator. The more are agreed these spaces, so it is more convenient to work the operator, thereby increasing the quality of work of system operator-manipulator.

When teaching the robot using the traditional method of coordinate control moving of the defining handle and moving of the manipulator robot executive hand is connected by law to [2]

$$\bar{y} = k\bar{x}, \tag{1}$$

where $\bar{x}$ is n - dimensional vector, $\bar{y}$ is n - dimensional vector, k is $n\times n$ - diagonal matrix, n is the dimension of the workspace of the robot actuator mechanism. In this case, the parameters of the matrix are constants, do not change in the control process.

For a system with continuous changes of parameter we consider the case of coordinate-parametric control [2]. Then the formula (1) will have the form

$$\bar{y} = k(t)\bar{x}, \tag{2}$$

where $k(t)$ is $n\times n$ - diagonal matrix of variable parameters. From the expression of velocity

$$\frac{d\bar{y}}{dt} = k\frac{d\bar{x}}{dt} + \bar{x}\frac{dk}{dt}$$

for providing mnemonic control [1] should be excluded summand $\bar{x}\dfrac{dk}{dt}$. Integrating this expression, we find the control algorithm

$$\bar{y} = \int_0^t k(\tau)\dot{\bar{x}}(\tau)d\tau + y_0. \tag{3}$$

The formal condition of the mnemonics of coordinate-parametric control is a condition of collinearity of vectors $\bar{y}$ and $\bar{x}$ [1], i.e. the condition

$$d\bar{y} = \alpha d\bar{x}, \tag{4}$$

where α is the diagonal matrix with constant equal coefficients. Consider the differential form of equation (2) together with (4) for the scalar case

$$\begin{cases} dy = kdx + xdk, \\ dy = \alpha dx. \end{cases} \tag{5}$$

Solving the system (5), we find

$$dy = \frac{\alpha}{\alpha - k} xdk.$$

Integrating both sides of this equation, we obtain

$$y = \int_0^t \frac{\alpha}{\alpha - k}\dot{k}xdt. \tag{6}$$

The condition of invariance of the output signal with respect to time is equality to zero of the derivative

$$\frac{dy}{d\alpha} = \frac{d}{d\alpha}\int_0^t \frac{\alpha}{\alpha - k}x\dot{k}dt.$$

We denote

$$f(\alpha,t) = \frac{\alpha}{\alpha - k}x\dot{k},$$

$$\frac{\partial f(\alpha,t)}{\partial\alpha} = -\frac{x\cdot k\dot{k}}{(\alpha - k)^2}.$$

If the functions $f(\alpha,t)$, $\dfrac{\partial f(\alpha,t)}{\partial\alpha}$ are continuous on the set $0 \le t \le 1$, $0 \le \alpha \le k_{\max}$, then

$$\frac{d}{d\alpha}\int_0^t f(\alpha,t)dt = \int_0^t \frac{\partial f(\alpha,t)}{\partial\alpha}dt.$$

The functions $f(\alpha,t)$, $\dfrac{\partial f(\alpha,t)}{\partial\alpha}$ have the discontinuity at the point $\alpha = k$. Consequently, at $\alpha \ne k$ we have

$$\frac{dy}{d\alpha} = -\int_0^t \frac{kx\dot{k}}{(\alpha - k)^2}dt.$$

This shows that $\dfrac{dy}{d\alpha}$ tends to zero, when α tends to infinity, practically greatest invariance is achieved at a choice of α in (6) at the upper boundary of the change interval of k, i.e. at $\alpha = k_{\max}$.

Consider the expression obtained by differentiating the formula (2)

$$\dot{y} = k\dot{x} + \dot{k}x,$$

and divide both sides of this equation by x, then we have

$$\dot{k} + k\frac{\dot{x}}{x} = \frac{\dot{y}}{x}.$$

We denote $f(t) = \dfrac{\dot{x}}{x}$, $g(t) = \dfrac{\dot{y}}{x}$ and obtain

$$\dot{k} + f(t)k = g(t).$$

This is the first order linear differential equation, allowing the integrating factor $\mu = \mu(t) = e^{\int f(t)dt}$.

The general solution of the equation has the form

$$k = \frac{1}{\mu(t)}\left[\int g(t)\mu(t)dt + C\right],$$

where $\mu(t) = e^{\int f(t)dt} = |x|$.

Then the value of k can be written as

$$k = \frac{1}{|x|}\left[\int \frac{\dot{y}}{x}|x|dt + C\right].$$

Substituting $\dot{y} = \alpha\dot{x}$ of (4), we obtain

$$k = \frac{1}{|x|}\left[\int \alpha|x|dt + C\right]. \tag{7}$$

Thus, the formula (7) gives the algorithm allowing to organize the automatic determination of the parametric signal that provides the unloading of the operator from one of control channels and simplifies his work, therefore improves the reliability of the manual control system.

For further research is used, firstly, the simplified case of the algorithm of coordinate-parametric control, which is written by the formula (3). Secondly, the algorithm of coordinate-parametric control, which basis is formula (7). For simplicity of the calculations is taken version of the algorithm (7) without integrals.

$$k = \alpha |\dot{x}|. \tag{8}$$

The difference between these two algorithms is that in the first algorithm the transmission coefficient is set by the operator by acting on the manual control. In the second algorithm, the coefficient is directly proportional to the speed, automatically applied to the input control system.

The structure of the block of coordinate-parametric control implementing of the algorithm (3) is shown in Fig. 1.

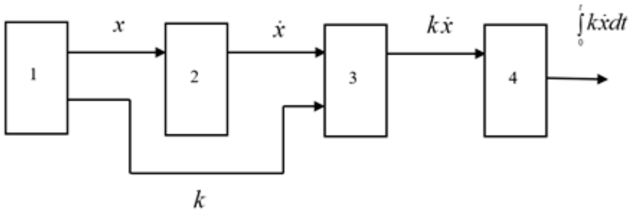

Fig. 1 The structure of the block of coordinate-parametric control: 1- master device, 2-differentiating device, 3-circuit of multiplication, 4- integrator

Human operator is produces by the master device a control signal U_x, which varies as shown in Fig. 2. In carrying out transport operations a person works with a large gain coefficient U_k, when performing of guidance operations with a small coefficient U_k. As a result of multiplying the signals $U_{\dot{x}} U_k$ we obtain the signal $U_{k\dot{x}}$, which is supplied to block integrator. With the integrator block coming out the signal $U \int_0^t k\dot{x}dt + C$, the form of which is shown in Fig. 2.

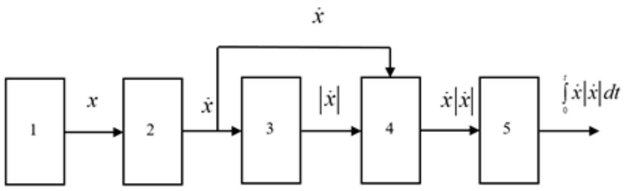

Fig. 2 The structure of the block of coordinate-parametric control with auto-tuning: 1- master device, 2-differentiating device, 3- circuit of module, 4-circuit of multiplication, 5- integrator

The resulting control law allows perform the master device small sizes and implement transport operations and guidance operations with great speed and high accuracy. The structure of the block of coordinate-parametric control with auto-tuning implementing of the algorithm (7) is shown in Fig. 3. A distinctive feature of the coordinate-parametric control system with auto-tuning (automatic), as compared to the coordinate-parametric control, is to use of control of transfer coefficient of the whole system. This feature allows to unload the human operator and improve parameters of the whole system [2].

3. Seminatural investigations of the training device of industrial robot

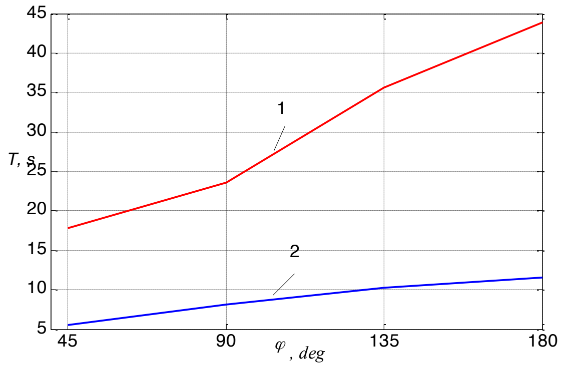

Fig. 3 The graph of laboratory tests: Tolerance =±0,2mm; 1 – the remote of manual control; 2 – coordinate-parametric control system

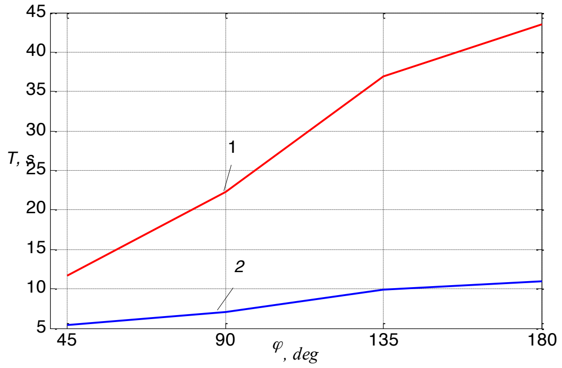

Fig. 4 The graph of laboratory tests: Tolerance =±0,5mm; 1 – the remote of manual control; 2 – coordinate-parametric control system

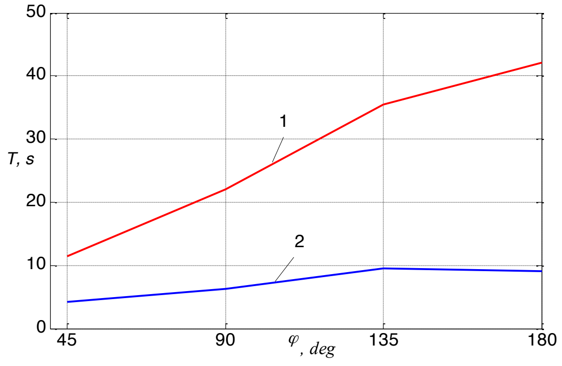

Fig. 5 The graph of laboratory tests: Tolerance =±1mm; 1 – the remote of manual control; 2 – coordinate-parametric control system

4. Conclusions

When tested with the coordinate-parametric control system the results in three different levels of accuracy were obtained. For comparative analysis the test results were also obtained with the command control system.

As a result of the conducted tests revealed that at learning of an industrial robot the use of coordinate-parametric control system reduces the time an average of 2.5 times as compared to the command control system for given level of accuracy.

In conducting of the laboratory tests the allowable error of the measured parameters of system is considered to be the value no more than 5%.

References

1. **Medvedev V.S., Leskov L.T., Yushchenko A.S.** 1978. The control system of manipulator robots. – M .: Nauka, 416 p. (in Russian).
2. Robotics. Coll. of Articles 1984./ Edited by **Popov E.P., Yurevich E.I.** - M.: Mechanical engineering. 288 p. (in Russian).
3. **Kuleshov V.S., Lakota N.A., Andryushin V.V.** 1986/ Edited by Popov E.P. Remotely controlled robots and manipulators - M.: Mechanical engineering. 328 p. (in Russian).
4. **Voznesensky S.P.** 1984. The problem of coordinate transformation in programming of industrial robots. - L. 11 p. Manuscript (in Russian).
5. **Petrov B.A.** Manipulators. 1984. L.: Mechanical engineering. 238 p. (in Russian).
6. Manipulator with remote control. – Application № 49-27817. Japan.
7. **Dzholdasbekov U.A. and others**. The device of the training of industrial robot. – Copyright certificate № 3700777/08 of 28.08.84.
8. **Tuleshov A.K., Ozhikenov K.A.** 2012. Modeling the dynamics of manipulators with the coordinate-parametric control: Monograph. Almaty.190 p. (in Russian) Available from Internet: http://portal.kazntu.kz/files/publicate/2015-10-12-11845_2.pdf.

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Summary

In the article conducted the development of algorithm of manual control system. As a such systems are used the system with coordinate-parametric control. The coordinate-parametric control algorithms of training of manipulator robots are obtained, they are based on the use of the mnemonic control concept. Graphs of time of moving the operating point to the target depending on the angle of rotation for the three different levels of accuracy are constructed. It was revealed that at training of an industrial robot the use of coordinate-parametric control system reduces the time an average of 2.5 times as compared to the command control system for given level of accuracy.

The results obtained in laboratory tests can be used to designing of systems of the manual teaching of industrial robot.

Keywords: systems of the manual training of industrial robot, coordinate-parametric control

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