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Synthesis of system for program signals formation for electric drives of multilink manipulators

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Abstract. The paper is devoted to the problem of synthesis of system for formation of input signals for actuators of multilink manipulators. This method provide movement of working tools with the maximum speed depending on the location of processed objects in the working area of manipulator without decrease of the set dynamic accuracy. In addition method provides an approach to the objects without overshooting.

1. Introduction

Robotics equipment used in modern industry has to perform working operations as quickly as possible and moving of the working tool (WT) from one detail or item to another should be smooth with exact stop near working objects without overshooting.

Currently at WT trajectory forming points of the working area is interpolated by splines not less than third order. And if necessary to ensure smooth movement the order of splines can be increased up to the fifth (see [1]). Because of arbitrary and constantly changing coordinates of details in the working area of manipulators computational load on the control computer increases significantly. In this case to maintain the required accuracy of the WT movement in all parts of the trajectory the average speed of their movement is often especially slows down, tuning on the most negative case in order to avoid reject in some parts of these trajectories even when it can be significantly increased. As a result performance of the manipulator is decreases.

In [2] a method of planning the trajectories of the manipulator WT using the four order B-splines is considered. To set these splines multi-parametric optimization algorithm is used. But the algorithm has a very high computational complexity which requires the use powerful processors to implement the control in real time.

In [3] the control system (CS) synthesis method for movement mode of the underwater vehicle which automatically generates a maximum current speed of its movement along spatial path with a given dynamic accuracy is considered. However, for effective use of the CS for the multilink manipulator one have to consider kinematic and dynamic features and then continuously determine the deviation of the working tool from the given trajectory. And this is very complicated during the manipulator movement.

In [4] and [5] a method of turning of program signals parameters of one degree of freedom manipulator movement is offered. It is based on the amplitude-frequency characteristics of manipulator actuators and provides maximum possible speed without reducing given dynamic accuracy. This method can be applied for the synthesis of system for formation of program signals of multilink manipulators motion, but one have to take into account the kinematic and dynamic features of the considered dynamic control object and continuous change its configuration during the execution of the required process steps.

2. Task Settings

The main goal of this paper is designing of the synthesis method of easy realizable control systems for multilink manipulators. These systems depending on the current location of processing objects have to form such input signals for all actuators which will provide movement of WT as quickly as possible and for given dynamic accuracy. The approach to the objects must be performed smoothly and without overshooting.

3. Description of the control object

Synthesis of the proposed system let us consider on two degree of freedom manipulator 1 (see fig. 1) making technological operations with objects 2 located on a pallet 3 which is located in the working area of the manipulator. A new pallet is moved in the working area of the manipulator each working cycle and location of objects is differing from the previous one. Working operations with all objects are performed only when the WT speed with respect to them is zero. Camera 4 is over the pallet and allows to determine the current location of all objects in it (coordinates x_j and y_j in the absolute coordinate system Oxy, where j - the number of objects on a pallet).

Actuators of the manipulator (see fig. 1) are DC drives with separate excitation or permanent magnet. Considering differential equation of the DC drive anchor circuit and its torque equations (see [6]) and interactions between all degrees of freedom (see [7]) the i-th actuator can be described by the equation (where the index i is omitted for convenience):

$$\begin{aligned} &L(J_\Sigma + H^*)\dddot{\alpha} + (L\dot{H}^* + Lh^* + RJ_\Sigma + RH^*)\ddot{\alpha} + (Rh^* + L\dot{h}^* + K_\omega K_M)\dot{\alpha} + \\ &+ R(M_C + M_{ex}^*) + L(\dot{M}_C + \dot{M}_{ex}^*) = K_M K_y u, \end{aligned} \tag{1}$$

where R, L - resistance and inductance of an anchor chain of actuator respectively; K_M, K_ω - torque and emf coefficients respectively; K_y - gain coefficient; u - input signal; $H^* = H(q)/i_p$; $h^* = h(q,\dot{q})/i_p$; $M_{ex}^* = M_{ex}(q,\dot{q},\ddot{q})/i_p$; $H(q)$ - component characterizing the inertial properties of the corresponding degrees of freedom of manipulator; $h(q,\dot{q})$ - component of the Coriolis force; $M_{ex}(q,\dot{q},\ddot{q})$ - torque influence, taking into account the gravitational forces and the effects of interaction between all the degrees of freedom of manipulator during its motion; i_p - gear ratio; $q_i, \dot{q}_i, \ddot{q}_i$ - generalized coordinates, velocities and accelerations of manipulator links respectively ($i = 1$, 2 - number of degrees of freedom of manipulator); J_Σ - moment of inertia of the rotating parts of the motor and gear unit; $\dot{\alpha}$, $\ddot{\alpha}$ - velocity and acceleration of the DC motor shaft respectively; M_C - Coulomb friction.

To provide the invariance of the quality of each actuator to the effects of interaction between all the degrees of freedom of moving manipulator (to stabilize their parameters and hence the coefficients of (1) at a nominal level) in each CS were added self-turning corrective devices described in [7].

To provide the required quality of work to both direct chains of actuators with already stabilize parameters were added standard corrective devices with transfer functions (see [6]):

$$W_{ki}(s) = (T_{1i}s + 1)/(T_{2i}s + 1), \tag{2}$$

where T_{1i} and $T_{1i} > T_{2i}$ - time constants that depend on the particular characteristics of DC drives. Their choice will be explained below.

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4. Program signals forming for actuators of manipulator

The algorithm of work of the proposed system is described below.

After determining the coordinates (x_j, y_j) of j-th item in the working area a two-link manipulator 1 by means of camera 4 (see fig. 1) and solving the inverse kinematics problem by method described, for example in [8], it is easy to find generalized coordinates $\tilde{q}^*_{1j}(x_j, y_j)$ and $\tilde{q}^*_{2j}(x_j, y_j)$. In trivial case for transfer of the manipulator WT from one item to another one can form the actuators input signal as a sequence of steps 1 (see fig. 2) corresponding to calculated generalized coordinates.

However, as shown in [4] and [5], than input signal is the sequence of steps it is necessary to significantly increase performance time of each stages of a running cycle specially limiting essentially increasing current in windings of electric drives in a start of motion and to provide the acceptable value of overshooting.

But the high quality of the transients and the required accuracy in the system can be achieved using simple regulators (2), forming the program signals as a sections of smooth curves (parts of harmonic signals). As these signals in paper is offered to use the sections harmonic curves of different frequencies (see curve 2 in fig. 2):

$$q^*_{ij} = \begin{cases} A_{pij}(1 - \cos(\omega_{pij}\tilde{t}_j)) + \tilde{q}_{i,j-1}, \text{if } \tilde{t}_j \leq \pi/\omega_{pij}; \\ 2A_{pij}, \text{if } \dot{q}^*_{ij} = 0, \dot{q}^*_{kj} \neq 0, i \neq k, \end{cases} \tag{3}$$

where A_{pij}, ω_{pij} - amplitudes and frequencies of program signals q^*_{ij}; $\tilde{t}_j$ - performance time of j-th working operation, which is cleared at the beginning of everyone operation; $\tilde{q}_{i,j-1}$ - generalized coordinates of manipulator links, corresponding to location of its WT at j-1-th item. It is assumed that the transient time in all manipulator actuators less than WT moving time from one place to another.

In the beginig of the working cicle the manipulator is in initial position in which $q^*_{i0} = 0$. The amplitudes of input signals for actuators are calculated according to $A_{pij} = 0.5(\tilde{q}_{ij} - \tilde{q}_{i,j-1})$. In [4] and [5] are shown that without reducing the accuracy of the dynamic control the frequency ω_{pij} can be changed depending on the current parameters of manipulators and amplitudes of harmonic input, essentially increasing working speed and accordingly the performance of the technological equipment without changing the structure and parameters of used regulators. The value ω_{pij} for the next move of the WT can be calculated as follows

$$\omega_{pij} = \frac{\sqrt{-1 + \sqrt{1 + 4T_i^2 K_i^2 \varepsilon_{di}^2 A_{pij}^{-2}}}}{T_i\sqrt{2}}, \tag{4}$$

where $T_i = 0.5T_{3i} + \sqrt{0.5T_{3i}^2 - T_{4i}}$; $T_{3i} = R_i J_{\Sigma i}/K_{Mi}K_{\omega i}$; $T_{4i} = L_i J_{\Sigma i}/K_{Mi}K_{\omega i}$; $K_i = K_{yi}/K_{\omega i}i_{pi}$; ε_{di} - given dynamic error of WT moving.

In this case at movement of WT from one object to another during one cycle the i-th actuator of the manipulator according to (3) will move along part of the harmonic path at maximum frequency (speed) (4). Thus each of the two motors have to work out an angle $2A_{pij}$, when turn is finished one of them stops expecting a stop of another.

5. Results of simulation

The installation process of some details on six objects placed on a pallet (see fig. 1) by the manipulator was investigated during the simulation. These details were located in the manipulator part magazine. The manipulator links with the same lengths $l_1 = l_2 = 0.4$ m were moved by identical DC motor with the following parameters K_y=800, K_M=0.02 N $\cdot$ m/A, K_ω=0.02 V $\cdot$ s, R=0.4 Ω, L=0.004 H, T_1=0.07 s, T_2=0.0035 s, $i_p = 100$.

In the initial position of the manipulator $q^*_{i0} = 0$, that is all its link located along axis y. Its WT (part magazine) consistently approaches to items that are placed on a pallet at the following points: (-0.7;0.1), (-0.15;0.65), (-0.6;0.3), (0.1;0.7), (0.2;0.5), (0.1;0.4). J_Σ remains unchanged and equal to 0.0005 $\mathrm{kg} \cdot \mathrm{m}^2$ due to using self-turning CS [7] and $\varepsilon_d = 0.0015$ rad.

On figure 3 input program signals for manipulator actuators are shown. They formed by the proposed system according to (3) and the considered technique. On figure 4 the laws of change of ω_p in above input signals are shown, they are calculated using (4).

Fig. 3 shows that when moving to the first item the first link of the manipulator needs to work out almost twice larger angle than its second link. That is the amplitude of the input signal to the first actuator is twice more than amplitude of the signal applied to the second actuator. Therefore to save the given accuracy of the WT approach to the item (see fig. 5) CS automatically reduces the frequency (speed) of rotation of the first link using (4). As a result the second link without exceeding set value ε_d turns on a given angle with greater speed, stops and waits for the approach of the first link. Figure 3 also shows that the first link rotates faster and expect the second when moving to the fifth item.

It should be noted that the greatest increase (4-9 times) ω_p (see fig. 4) is observed when links turn on angles less than 30 degrees. The study showed if program signals is forming according to (3) and ω_p according to (4) then total run time with six items is 19.7 s. If ω_p is selected as constant taking into account the required accuracy then total time increases to 30.5 seconds. And finally if the inputs of all actuators are step signals then run time of this work increases to 55 s, taking into account that the next step on the corresponding actuator will be formed only when the steady-state error will not exceed ε_d=0.0015 rad. That is by means of turning only ω_p one can improve the performance of the whole system up to 1.55 times and by means of harmonic signals this performance can be improved up to 2.79 times. The above confirms the high efficiency of the developed system allowing to form program signals for actuators of multilink manipulators as segments of harmonics with variable amplitude and turning frequency.

6. Conclusion

The paper proposes a synthesis method of systems for forming program signals for actuators of multilink manipulators. It allows to provide movement of manipulator links with the maximum speed (frequency) and given level of dynamic accuracy. This provide a smooth approach of the manipulator working tool to the object (item) without overshooting. The implementation of the proposed system is not difficult.

Acknowledgments

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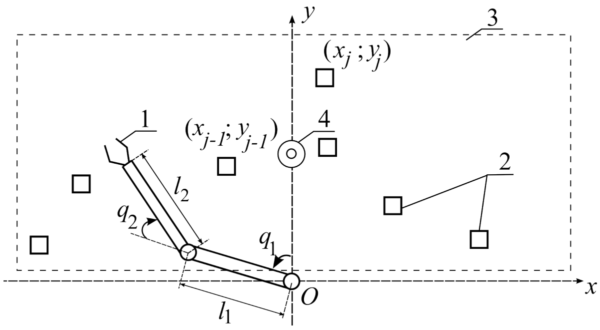

Figure 1. Scheme of technological process

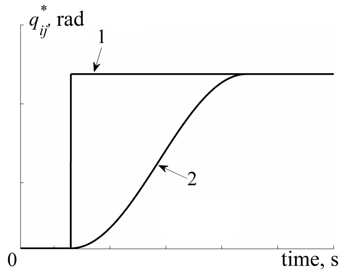

Figure 2. Forms of the input signals

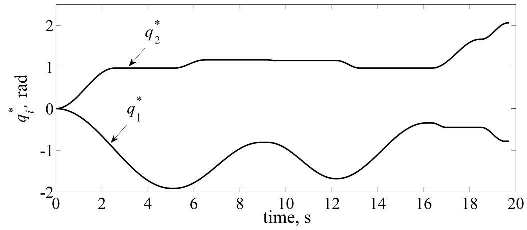

Figure 3. Input program signals for manipulator actuators

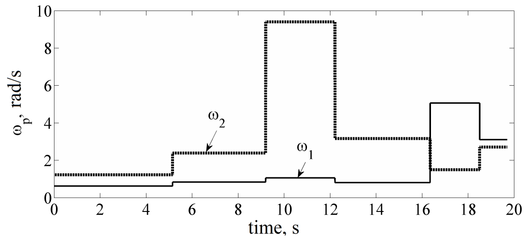

Figure 4. Frequencies of input signals

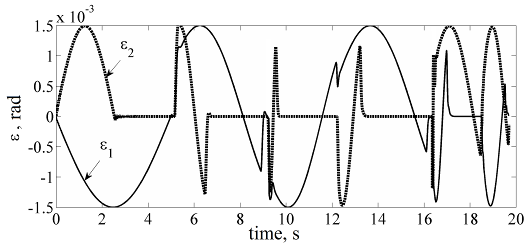

Figure 5. Dynamic errors