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Influence of gripper's motion on control synthesis of manipulator dynamics*

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I. Introduction

In practice, control synthesis of manipulators in point-to-point operations is performed one by one for each joint or with kinematical control on a trajectory connecting the initial and terminal positions. These methods cannot take into account dynamical interactions between the manipulator parts which is of great significance in the presence of higher velocities, accelerations and inertial characteristics.

Control system must operate in such a way that the main qualities of these handling manipulations can simultaneously be achieved:

— time-optimal travelling between programmed locations,

— smooth positioning,

— settling in programmed positions with desired accuracy.

In the present work, on the basis of a recently proposed method for control synthesis in point-to-point operations [1], the influence of gripper's kinematics on the dynamic regional motion has been investigated. The overshooting is shown on a model of a robot in the case when the changing of gripper's configuration is not taken into account. Finally, the motion of gripper being given, the control synthesis of the time-dependent regional system has been performed.

II. Synthesis of point-to-point control

The mathematical model of a manipulator with „n" degrees of freedom incorporating all relevant kinematic and dynamic parameters is presented by a system of complex non-linear differential equations:

$$M(q)\ddot{q}+N(q,\dot{q})=R(t) \tag{1}$$

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where: $q(t) \in R^n$ is a vector of generalized (joint) coordinates of the mechanical system, $M(q)$ is an inertial matrix, $N(q, \dot{q})$ is a vector of centrifugal, Coriolis and gravity forces, $R(t) \in R^n$ is the vector of driving forces or torques.

Denote by:

(2) $$q(t^0) = q^0, \; \dot{q}(t^0) = 0 \text{ — initial phase position}$$

(3) $$q(t^f) = q^f, \; \dot{q}(t^f) = 0 \text{ — final phase position.}$$

Each control function $R_i(t)$, $(i = 1, \ldots, n)$, has one switching time t_i^s (from acceleration to deceleration).

For the sake of a clearer understanding of the method, a relay form of R_i [1] will be assumed:

— acceleration regime: $R_i = \text{sign}_i \, R_i^a$, $t \in (t^0; t_i^s)$

— deceleration regime: $R_i = \text{sign}_i \, R_i^d$, $t \in (t_i^s; t_i^f)$,

where: $\text{sign}_i = \text{sign} \, \dot{q}_i = \text{sign} \, (q_i^f - q_i^0)$, $i = 1, \ldots, n$.

The values R_i^a and R_i^d are to be extremal via time-optimal concept of Pontrjagin's maximum principle, but permissible as regards the requirement of smooth positioning or other technical constraints.

It is assumed that the following uncoupled contrallability conditions on system (1) are to be fulfilled:

(4) $$\text{sign} \, R_i = \text{sign} \, \ddot{q}_i = \text{sign} \, [M^{-1}(q) R - M^{-1}(q) N(q, \dot{q})]_i, \; i = 1, \ldots, n.$$

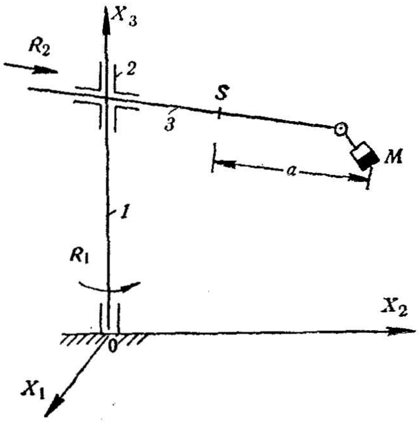
Since there is strong monotony of the functions $q_i(t)$, the switching times t_i^s, $(i = 1, \ldots, n)$, one-to-one correspond to some values q_i^s (switching values) of the joint coordinates q_i.

Then, the system of differential equations (1) is integrated with the initial conditions (2) and some approximate switching values q_i^s, $(i = 1, \ldots, n)$, until satisfying the terminal conditions $(3)_2$, i. e., $\dot{q}_i(t_i^f) = 0$, $t^f = \max \, t_i^f$, $i = 1, \ldots, n$. This action symbolizes a movement of the manipulator from the given initial position to an approximate final position. The final values $q_i(t_i^f) = F_i$, $(i = 1, \ldots, n)$ are functions of n-dimensional vector q^s. Further, the problem consists in the interative adjustment of the switching values in order to satisfy the other required final condition $(3)_1$, i. e., the two-point boundary-value problem $(1 \div 3)$ is reduced to the shooting equation $F(q^s) = q^f$, that is solvable using the relevant, well-known methods [2].

It can be seen that the algorithm of the proposed method is workable in more general cases when the control functions in each separate regime are given as non-linear functions of the correspondent generalized coordinates, including delay and friction effects etc., as well. Moreover, if the identification of the parameters in system (1) is not sufficiently exact, then this shooting method can be realized on the robot-manipulator itself.

III. Control synthesis of manipulator with cylindrical coordinates and rotation of its gripper

On the basis of the above proposed method, the influence of the gripper kinematics on the dynamic behaviour of regional structure of the manipulator in point-to-point operations will be investigated. Simultaneous doing of joint motions is necessary for reducing the total duration of each such operation. If we do not take into account the orientation of the comparatively massive gripper (including handled mass), then in fast point-to-point operations, overshooting may occur.



Фиг. 1

The dynamical model of the regional structure of a manipulator in cylinfrical coordinates, according to the Fig. 1, can be written in the following orm [1,3]:

$$\{[J_1+J_2+mq_2^2+M(q_2+a)^2]\dot{q}_1\}^{\cdot}=R_1(t) \tag{5}$$

$$(m+M)\ddot{q}_2-[mq_2+M(q_2+a)]\dot{q}_1^2=R_2(t)$$

(the vertical translation is independent of the rotation and horizontal translation), where: (q_1, q_2) are polar coordinates of the mass centre S of the link 3, M is the total mass of the gripper and handled object, m — mass of the link 3, J_1 — total momentum of inertia of the link 1 and 2 with respect to the X_3-axis, J_2 — momentum of inertia of the link 3 with respect to the axis that passes through the point S and parallel to the X_3-axis, a — distance between the M mass centre and S.

The numerical considerations have been carried out with the following values of the parameters:

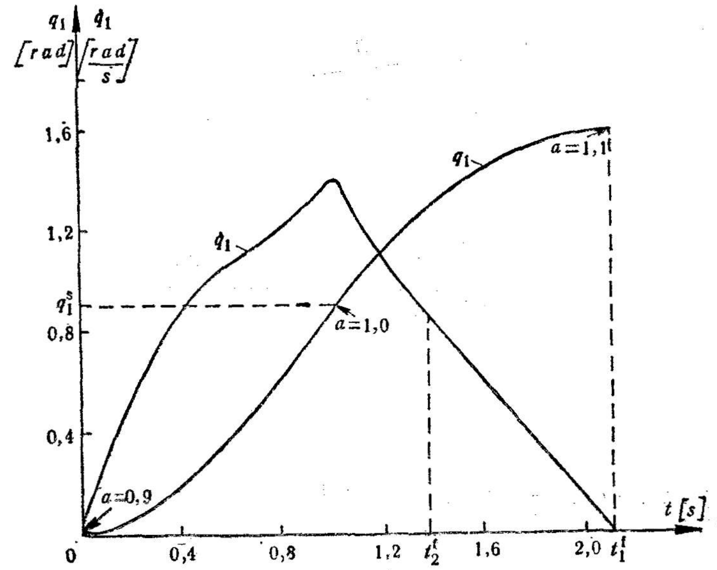
$m=97\,[kg]$, $M=50\,[kg]$, $a=0{,}9\div1{,}1\,[m]$, $J_1+J_2=193[kg\,m^2]$, $R_1^a=-R_1^d=600[Nm]$, $R_2^a=-R_2^d=500\,[N]$, $t^0=0\,[s]$, $q_1^0=0\,[rad]$, $q_2^0=0\,[m]$, $q_1^f=1{,}571\,[rad]$, $q_2^f=1{,}0\,[m]$

Table 1

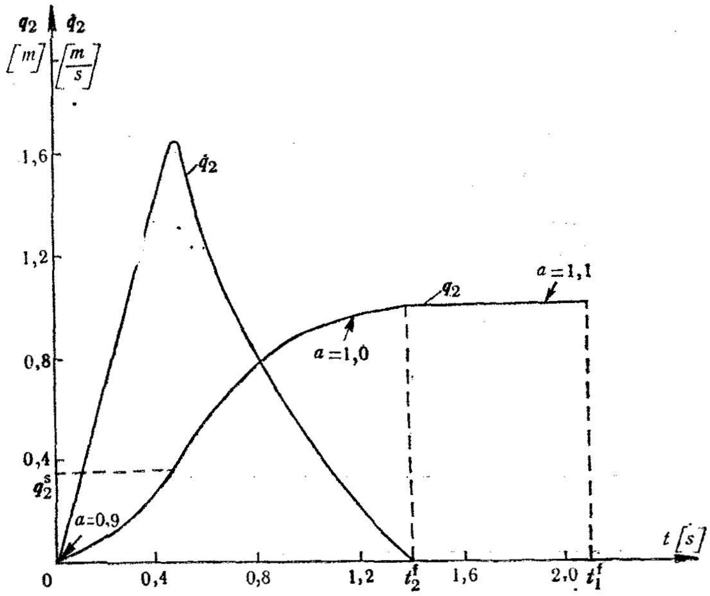
a	q_1^S	q_2^S	F_1	F_2
0.9	0.904	0.357	1.571	1.000
1.1	0.896	0.369	1.571	1.000
0.9÷1.1	0.904	0.357	1.600	0.965

The system (5) has been integrated by a fourth-order Runge-Kutta method. A good convergence in iterative corrections of $q_i^s (i=1,2)$ is provided due to the existence of the controllability condition (4).

In the first two lines of Table 1 exact switching values for the extreme values of „a" respectively are given. In the third line, the overshooting, that



Фиг. 2



Фиг. 3

occurs if changing of the parameter „a" (from 0,9 up to 1,1) is not taken into account in control synthesis, is shown.

Now, let the gripper moves together with the regional structure of the manipulator. Therefore, the parameter „a" will be time-varying and we have to make control synthesis of time-dependent system (5).

The exact execution of joint motions, which is obtained by the proposed shooting method, is shown on Fig. 2 and 3, provided that the parameter „a" varies linearly from 0,9 up to 1,1.

IV. Conclusions

By the help of the recently proposed shooting method, the main qualities of manipulator operations can be achieved: smooth positioning and desired accuracy. The influence of gripper's configuration on the regional motion has been shown on a manipulator model. Then, the motion of gripper being given, the method is applied for control synthesis of the time-dependent regional system.

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