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Control Synthesis of Manipulator Dynamics in Handling Operations

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1. Introduction

At the present time, control synthesis of manipulators in handling operations is performed one by one for each joint [1] or by teaching on a trajectory, connecting the initial and terminal states. These methods can not take into account dynamical interactions between the segments of manipulator which is of great significance in the presence of higher velocities, accelerations and inertial characteristics. So, at the same time, it is impossible to get the importan qualities in handling operations: minimal time operation, light stoppage and po sitioning accuracy.

In the present paper a general method for control synthesis of manipulators in handling operations is suggested. This method is based on the exact nonlinear dynamic equations. The switching values (from acceleration to deceleration) of the joint coordinates are found by several repeated integrations of the system of the dynamic equations. The proposed method is applied to Versatran manipulator with cylindrical coordinates.

2. Mathematical statement of the problem

Dynamic equations of the manipulator with "n" degrees of freedom can be written in the form [2]

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

where $q(t)\in R^n$ is a vector of joint coordinates, $M(q)$ is a symmetrical, positive definite inertial matrix, $R(t)\in R^n$ is a vector of control forces, $N(q, \dot{q})$ is a vector of nonlinear interaction between the segments of manipulator.

Initial state;

$$q(t^0)=q^0,\ \dot{q}(t^0)=0. \tag{2}$$

Required terminal state:

$$q(t^f)=q^f,\ \dot{q}(t^f)=0. \tag{3}$$

Velocities signs condition:

$$\operatorname{sign} \dot{q}_i=\operatorname{sign}\ (q_i^f-q_i^0),\quad (i=1,\dots, n). \tag{4}$$

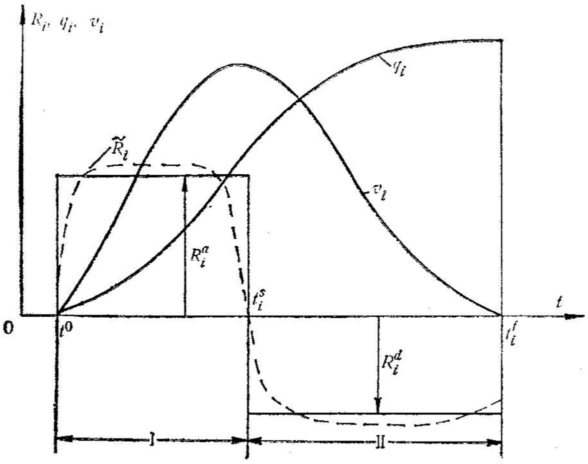

Fig. 1

The time-diagram of each joint coordinate q_i (t) with zero initial and final values of its velocity, having in mind the condition (4), can be divided in two steps. The first step of acceleration, in which $|\dot{q}_i(t)|$ increases from zero to maximum and the second step of deceleration, in which $|\dot{q}_i(t)|$ decreases from the reached maximum to zero, Fig, 1. $\tilde{R}_i(t)$ is a general appearance of the relevant control function. With the purpose of simply explaining of the method it will be assumed a relay form of R_i;
Acceleration step (I): $R_i = \text{sign}\ (q_i^f - q_i^0)\ R_i^a$:
Deceleration step (II): $R_i = \text{sign}\ (q_i^f - q_i^0)\ R_i^d$.

In the next consideration, simultaneous starting of the joint motions is supposed. The end of each motion is at the moment t_i^f which satisfies the condition $\dot{q}_i\ (t_i^f) = 0$.

In order to perform strong monotonous motion of each joint with zero initial and final values of its velocity, irrespective of the other motions, it is sufficient to be fulfilled (following [3]) the next natural control condition

(5) $$R_i\,[M^{-1}(q)R - M^{-1}(q)N(q, \dot{q})]_i > 0, \quad (i = 1, \ldots, n).$$

3. Control synthesis

Since the functions $q_i(t)$ are strong monotonous, $t_i^s\ (i = 1, \ldots, n)$ one-to-one correspond to some values q_i^s (switching values) of the joint coordinates. The system of differential equations (1) is to be integrated with initial conditions (2) and given switching values q_i^s until satisfying the terminal conditions $(3)_2$ $(t^f = \max\ t_i^f,\ i = 1, \ldots, n)$. Further the problem consists in determination of these values until satisfying the other required condition $(3)_1$. The final values $q_i(t_i^f) = F_i$ $(i = 1, \ldots, n)$ are functions of n-dimensional vector q^s. So the problem reduces to solving the following nonlinear vector equation

(6) $$F(q^s) = q^f.$$

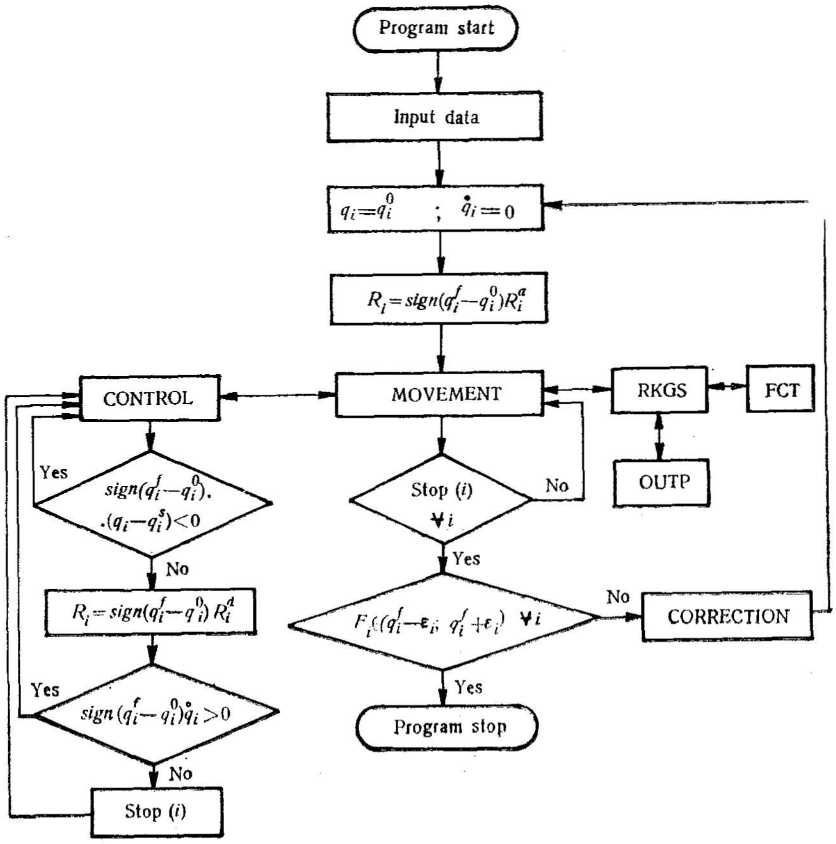

Fig. 2

The last equation (6) represents a two-point boundary value problem that can be solved using the well known iterative methods (of bisections, tangents and other).

The algorithm of the proposed method is shown in Fig. 2, where MOVEMENT symbolizes the manipulator motion from the initial to a terminal position by means of subroutine RKGS for numerical integrating of the system (1) (FCT and OUTP are subsidiary subroutines of RKGS) and by means of subroutine CONTROL that controls the motion of each joint; CORRECTION expresses the iterative correction of the switching values q_i^s until satisfying the accuracy condition

(7) $$F_i\,(q^s) \in (q_i^f - \varepsilon_i\,;\ q_i^f + \varepsilon_i), \qquad (i = 1, \ldots, n).$$

For the completely determination of the switching values of the joint coordinates, the proposed algorithm may be realized on the manipulator itself.

4. Illustrative numerical example

Dynamical model of Versatran type manipulator with two degrees of freedom is considered, Fig. 3 (the vertical translation is independent of the

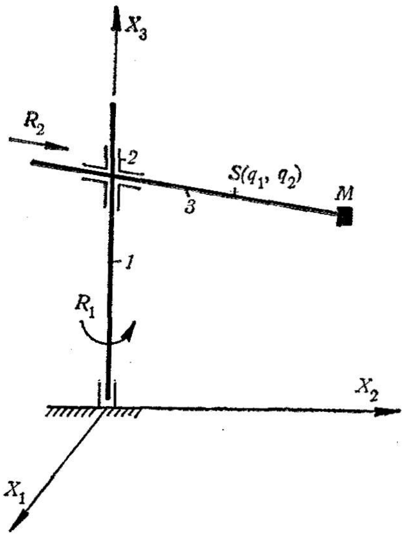

Fig. 3

rotation and horizontal translation). The equations of motion are as follows [4]:

$$(8)\qquad \{[J_1+J_2+m_2 q_2^2+M(q_2+a)^2]\,\dot q_1\}^{\cdot}=R_1(t),$$
$$(m_2+M)\ddot q_2-[m_2 q_2+M(q_2+a)]\dot q_1^2=R_2(t),$$

where: (q_1, q_2) — polar coordinates of the mass centre of the segment 3, M — total mass (mass of the gripper and the tip mass), m_1 — mass of the segment 2, m_2 — mass of the segment 3, J_1 — total momentum of inertia of the segments 1 and 2 about the X_3-axis, J_2 — momentum of inertia of the segment 3 about the axis which passes through the point S and parallel to the X_3-axis, a — distance between the mass centre M and S.

The following parameters are accepted:

$$m_1=210\ [kg],\ m_2=97\ [kg],\ M=100\ [kg],\ a=1\ [m],\ J_1+J_2=193\ [kgm^2],\ R_1^a=-R_1^d=400\ [Nm],$$
$$R_2^a=-R_2^d=400\ [N],\ t^0=0\ [s],\ q_1^0=0\ [rad],\ q_2=0\ [m],\ q_1^f=1\ [rad],\ q_2^f=1\ [m],$$
$$\varepsilon_1=0.01\ [rad],\ \varepsilon_2=0.01\ [m].$$

Table 1

No	q_1^s	q_2^s	F_1	F_2
1	0.56	0.45	0.9119	1.1073
2	0.661	0.349	1.1517	0.8684
3	0.611	0.401	1.0266	0.9942
4	0.559	0.401	0.9366	0.9847
5	0.585	0.449	0.9552	1.1136
6	0.609	0.425	1.0133	1.0561
7	0.598	0.401	1.0033	0.9928

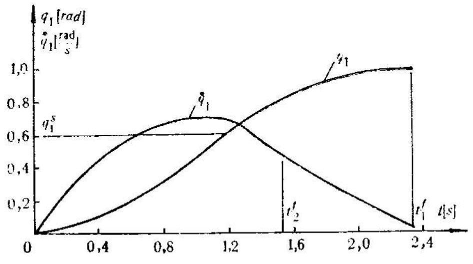

Fig. 4

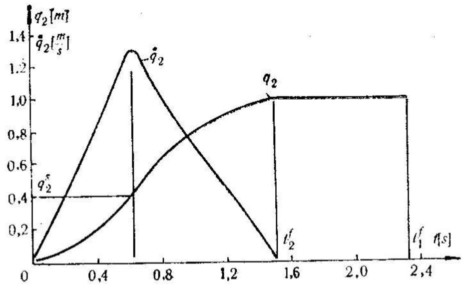

Fig. 5

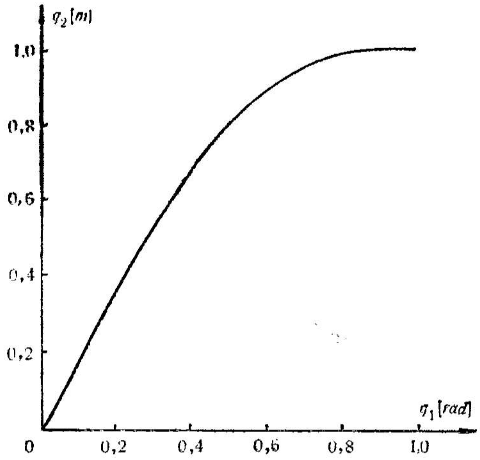

Fig. 6

The numerical simulation was performed on ES 1040 computer in about 3 minutes using FORTRAN IV programme. The iterative corrections and the corresponding final values of the joint coordinates are given in Table 1.

In consequence of the joint interactions, the obtained switching values considerably differ from those (0.5), which correspond to the case of one by one doing of the joint motions.

The execution of the motion with given positioning accuracy is shown in Fig. 4, 5 and 6.

5. Conclusions

a. A direct method for control synthesis of manipulator dynamics in handling operations has been suggested,

b. Applying this method it is possible to realize minimal time operation with light stoppage and positioning accuracy,

c. The method is workable also in the more general case of nonlinear control functions,

d. The proposed algorithm can be implemented in teaching of the manipulator itself.

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References

1. Spur G., H. Sinning, Problems in Real Time Controlling Motion of Handling Devices Third IFAC/IFIP Symposium on Control Problems and Devices in Manufacturing, Techology, 1980, p. 185-194.
2. Пол Р., Моделирование, планирование траекторий и управление движением робота-манипулятора, 1976, Наука, с. 103
3 Ковалев А., Нелинейные задачи управления и наблюдения в теории динамических систем, Наук. думка, 1980. с. 173
4 Потеев М., Л., Потеева Н., Жаботинский, Использование динамических уравнений промишленных роботов при их проектирования, „Изв. ВУЗ. Машиностроения“, № 1, 1979, стр. 39-42