ASSISTED RESEARCH OF THE INDUSTRIAL ROBOTS KINEMATICS WITH LABVIEW INSTRUMENTATION

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ABSTRACT

The paper presents one assisted method of the cinematic behaviour of the industrial robots. It is shown the general mathematical model for direct and inverse cinematic behaviour for the arm type robot. The paper contents the iterative matrix equations for the position, velocity and acceleration analyse. The assisted research is realised by using the virtual proper LabVIEW instruments (VI) according with the mathematical general model and working on-line. With these facilities is very easy to see what is the more important functional or constructive parameters in the cinematic behaviour and what was happened when is changed someone of it. In the paper with the matrix method are presented some cinematic characteristics when was changed the joints velocity characteristics or the different constructive parameters. Also was analysed the cinematic errors obtained with the simple command with the trapezoidal characteristics of the electrical tension of command with three constant steps. The presented method is generally; it is possible to apply in many other mechanical structures. The LabVIEW VI -s offer very important information what will be necessary in a dynamic behaviour analyse.

Keywords: cinematic analyze, cinematic errors, virtual instrumentation LabVIEW, assisted research

1. INTRODUCTION

For the purpose of the modelling, searching and validating the mathematical model, in the research laboratory of the Dynamic Behaviour of Industrial Robots of the faculty I.M.S.T.-U.P.B., there was designed and realized an arm type robot with five degrees of mobility as it is presented in figure 1. The robot is designed and realized in modular conception and continuous current drive of small power operates it. The reaction circuits are realized with the help of some tahogenerator velocity traducers for each degree of mobility. The command and the control are realized with a compatible computer IBM-PC foreseen with an acquisition board type PCI 6024E from National Instruments, USA. The amplification of the command signal is done with a block of power transistors of type 2N3055. The position reaction was originally realized with a photoelectric incremental traducer having the control on the serial port of the computer. The structure of the robot contain the way of rotation at base; the way of shoulder rotation; the way of elbow rotation; the way of pitch rotation; the way of roll rotation. The study of the cinematic behavior of the arm type robot was realized using the experimental installation being in the endowment of the laboratory in this way, in figure 1. There can distinguish the following components: didactical robot; stabilized source of continuous voltage; accelerometer; a block of amplifying the order signal; screen; computer; multimeter; connectors of the acquisition board type CB-68LP the acquisition board type PCI 6024E from National Instruments, USA,. The original IBM PC system has as support ROM-BIOS for three parallel ports. The studies realized until now illustrate that using a 'mouse' system as position traducer there can be commanded the engines of mechanical structure having at more four degrees of mobility, as well as an engine for operating the mechanical hand (when the position traducer is not needed). For simplifying the robot's assemble and

the program of command it is recommended that the operation drive of the mechanical structure to be first of all electric, preferable of continuous current.

2. GENERAL MATHEMATICAL MODELING OF THE ROBOTS CINEMATICS

In this paper are presented the mathematical model for the position analyze for the arm type robot [1,2,3,4]. In figure 1 are presented the researched robot witch was analyzed.

The iterative matrix mathematical model determined with the quaternion theory and the compound of the spatial vectors, for the positions, velocities and accelerations analyze are:

$$(\bar{r}_i^{(0)}) = (\bar{r}_{i-1}^{(0)}) + [D_{0,i-1}] \cdot (\bar{r}_i^{(i-1)}) \qquad (A_{i,i-1}^{(i)}) = \left| \frac{(\varepsilon_{i,i-1}^i) + [\hat{\omega}_{i-1,0}^i] \cdot (\omega_{i,i-1}^i)}{(a_{i,i-1}^i) + [\hat{\omega}_{i-1,0}^i]^2 \cdot (r_i^0) + 2[\hat{\omega}_{i-1,0}^i] \cdot (v_{i,i-1}^i)} \right| \qquad (1)$$

$$(\bar{w}_{i,0}^i) = [T_{i,i-1}] \cdot (\bar{w}_{i-1,0}^{i-1}) + (\bar{w}_{i,i-1}^i) \qquad [T_{i,i-1}] = \begin{bmatrix} [D_{i,i-1}] & [0] \\ -[\hat{r}_i^{i-1}] \cdot [D_{i,i-1}] & [D_{i,i-1}] \end{bmatrix}$$

$$(\bar{A}_{i,0}^{(i)}) = [T_{i,i-1}] \cdot (\bar{A}_{i-1,0}^{(i-1)}) + (\bar{A}_{i,i-1}^{(i)})$$

where: $(r_i^0), (r_{i-1}^0)$ are the matrices for the absolute position of i and i-1joint; $[D_{0,i-1}]$- the matrix for the transfer by rotation or translation of the vector from i-1 system to base system; $(w_{i,0}^{(i)}), (w_{i-1,0}^{(i-1)})$ the absolute dual matrices for the angular and linear velocity of the i and i-1 bodies; $[T_{i,i-1}]$- the matrix of the transfer dual vectors from i-1 to i joint; $(w_{i,i-1}^{(i)})$- the relative dual matrix for the angular and linear velocity; $(A_{i,0}^{(i)}), (A_{i-1,0}^{(i-1)})$- the absolute dual matrices for the angular and linear accelerations of the i and i-1 joints; $(A_{i,i-1}^{(i)})$- the relative dual matrix for the angular and linear acceleration.

3. THE ITERATIVE GENERAL DISPLACEMENT ERROR METHOD

The iterative method of the errors determination of the robot tool center point (TCP) trajectory is very generally, it is possible to apply for all robot types and for all space curves. This method consists in:
- the establishing the space Γ curve equation in the form:

$$f_{1-3}(x, y, z, x^2, y^2, z^2, \dots) = 0, \text{ or} \qquad (2)$$
$$f_1(x, y, z, x^2, y^2, z^2, \dots) = 0$$
$$f_2(x, y, z, x^2, y^2, z^2, \dots) = 0 \qquad (3)$$
$$f_3(x, y, z, x^2, y^2, z^2, \dots) = 0;$$

- the defining the first and the last point of the TCP trajectory of the curve Γ:

$\qquad P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2);$ (4)
- the checking if these positions of the TCP are in a robot workspace:

$\qquad P_1 \cup P_2 \in R^3_{RI};$ (5)

Figure 1.Experimental stand of the arm type robot to validate the mathematical model

- the establishing the iterative values of the x current position of the TCP, x_{crt} and all other coordinates y_{crt} and z_{crt} from the Γ curve space equation (2, 3):

$\qquad x_1 \leq x_{crt} \leq x_2; \quad y_{crt} = f_{y\_crt}(x_{crt}, z_1, x^2_{crt}, z_2, x_1, x_2, \dots); \quad z_{crt} = f_{z\_crt}(x_{crt}, z_1, x^2_{crt}, z_2, y_1, y_2, \dots)$ (6)
- the checking of the condition that the current position of the TCP is between the initial and final established coordinates of the Γ space curve: $\quad y_1 \leq y_{crt} \leq y_2; z_1 \leq z_{crt} \leq z_2;$ (7)
- from the TCP equations of the position it can to establish, for the first point $P_1(x_1, y_1, z_1)$, the initial value of the φ_i and for the final position $P_2(x_2, y_2, z_2)$ the angular value $(\varphi_i + q_{max})$ and for the current position of the TCP, $P_{crt}(x_{crt}, y_{crt}, z_{crt})$ the angular current value $(\varphi_i + q_{crt})$;
- the iterative process will be finished when the all iterative space between the x_1 and x_2 is routed;
- if the time of the movement between the first and the last position of the TCP on the curve Γ is established, we can to show the characteristics of the time variation of the all robot coordinates, q_i; -in the $\dot{q}_i$ characteristics we establish the trapezoidal characteristics of the movement what approximate

very well to the real one and the differences between them. These we were made with the scope to obtain the minimal velocity and position errors, to be able to compensate them by electrical feed back compensation:

$$\varepsilon_{cin} = \left| \dot{q}_i(t) - \dot{q}_{trap}(t) \right| \le \varepsilon_{adm};$$ (8)

-finally, the cinematic errors are compensated by the current infusion in the closed loop scheme.

4. DIRECT AND INVERSE CINEMATIC MODEL OF THE ARM TYPE ROBOT

After application of the (1) relations to the arm type robot on obtains the following relations for the TCP position:

$$x = l_2 s_1 s_2 + l_3 s_1 s_{23}; y = -l_2 c_1 s_2 - l_3 c_1 s_{23}; z = l_1 + l_2 c_2 + l_3 c_{23}.$$ (9)

where: $c_1 = cos(\varphi_{01}+q_1)$; $c_2 = cos(\varphi_{12}+q_2)$; $c_3 = cos(\varphi_{23}+q_3)$; $s_1 = sin(\varphi_{01}+q_1)$; $s_2 = sin(\varphi_{12}+q_2)$; $s_3 = sin(\varphi_{23}+q_3)$; $s_{23} = sin(\varphi_{12}+q_2 +\varphi_{23} +q_3)$; $c_{23} = cos(\varphi_{12}+q_2 +\varphi_{23} +q_3)$; l_i length of each body; q_i the robot coordinate; φ_{ij} the angular previous position between i and j body.

From two first equations of the relation (9) results the relative displacement in the joints:

$$\varphi_{01} + q_1 = arctg(-\frac{x}{y}); \varphi_{01_{(q_1=0)}} = arctg(-\frac{x_1}{y_1}); q_{1\_max} = arctg(-\frac{x_2}{y_2}) - \varphi_{01}; q_{1\_crt} = arctg(-\frac{x_{crt}}{y_{crt}}) - \varphi_{01}.$$ (10)

with the current intern robot coordinate:

$$q_{3\_crt} = -\arccos(\frac{x_{crt}^2 + y_{crt}^2 + z_{crt}^2 - 2z_{crt}l_1 + l_1^2 - l_2^2 - l_3^2}{2l_2 l_3}) - \varphi_{23}.$$ (11)

The current position of the TCP we defined from the condition: the point remain on the space curve of the robot trajectory, Γ. If this trajectory is one line in the workspace of the robot, the general equation of this curve is:

$$\frac{x_{crt} - x_1}{x_2 - x_1} = \frac{y_{crt} - y_1}{y_2 - y_1} = \frac{z_{crt} - z_1}{z_2 - z_1}.$$ (12)

The iteration process begins with the imposed first $x_{crt}=x_1$ and the second $x_{crt}=x_1+\Delta x \le x_2$ and other coordinate will be:

$$y_{crt} = \frac{y_2 - y_1}{x_2 - x_1}(x_{crt} - x_1) + y_1 \le y_2;$$

$$z_{crt} = \frac{z_2 - z_1}{x_2 - x_1}(x_{crt} - x_1) + z_1 \le z_2.$$ (13)

Finally, the current relative coordinate in the second Cartesian system will be:

$$q_{2\_crt} = 2arctg\frac{(l_2 s_1 + l_3 s_1 c_3) \pm \sqrt{(l_2 s_1 + l_3 s_1 c_3)^2 - (x_{crt}^2 - (l_3 s_1 s_3)^2)}}{x_{crt} + l_3 s_1 s_3} - \varphi_{12}$$ (14)
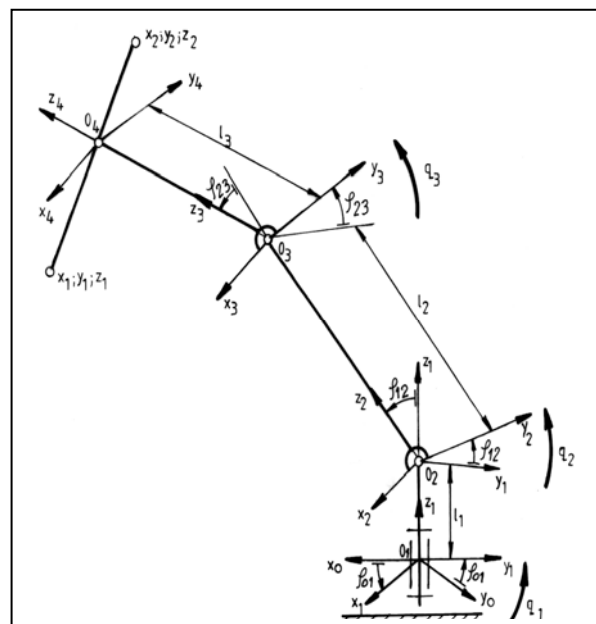

Figure 2. The cinematic- structural schema for the arm type researched robot

5. NUMERICAL SIMULATION WITH LABVIEW INSTRUMENTATION AND RESULTS

The numerical simulation was made with aid of the LabVIEW soft 6.1 from National Instruments, USA. The presented mathematical model was transpose in one LabVIEW *VI*. Some results of the simulation and the part of *VI* and the icon are presented in figure 3- 5. For the command velocity we was used the following characteristic, figure 3 and the part of C^{++} program (15).

After the analyze of the show characteristics we can do the following remarks: - the angular errors is possible to cancelled with the best chose of the command characteristics; - with a good precision

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if (t>=0.0 && t<t_a) qq2crt=(q_{c1}/t_a)*t;

if (t>=t_a && t<t_a+t_{c1}) qq2crt=q_{c1};   (15)

if (t>=t_a+ tc1 && t<t_a+t_{c1}+t_d)

   qq2crt=qq2ant-((q_{c1}-q_{c2})/t_d)*Δt;

if (t>= t_a+t_{c1}+t_d && t< t_a+t_{c1}+t_d +t_{c2}) qq2crt=q_{c2};

if (t>= t_a+t_{c1}+t_d +t_{c2} && t< t_a+t_{c1}+t_d +t_{c2}+t_{a_d})

   qq2crt=qq2ant-((q_{c2}-q_{c3})/t_d)*Δt;

if (t>= t_a+t_{c1}+t_d +t_{c2}+t_{a_d} &&

   t< t_a+t_{c1}+t_d +t_{c2}+t_{a_d}+t_{c3}) qq2crt=q_{c3};

if (t>= t_a+t_{c1}+t_d +t_{c2}+t_{a_d}+t_{c3} &&

   t< t_a+t_{c1}+t_d +t_{c2}+t_{a_d}+t_{c3}+t_{a_d})

   qq2crt=qq2ant-((q_{c3}-q_{c4})/t_d)*Δt;

if (t>= t_a+t_{c1}+t_d +t_{c2}+t_{a_d}+t_{c3}+t_{a_d} && t<

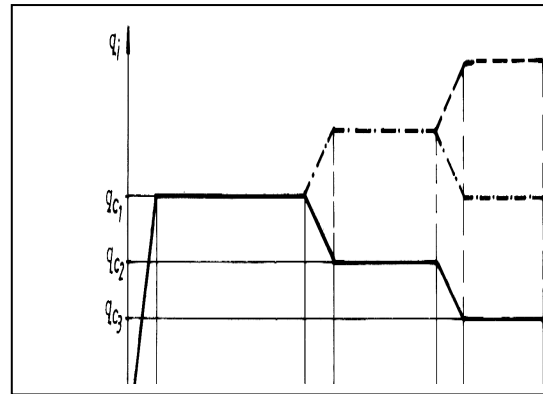 t_a+t_{c1}+t_d +t_{c2}+t_{a_d}+t_{c3}+t_{a_d}+t_{c4}) qq2crt=q_{c4};

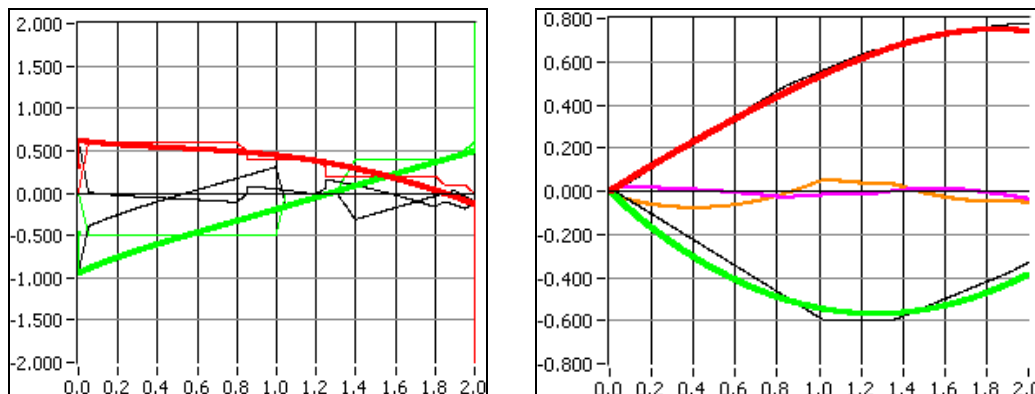Figure 4. Trapezoidal characteristic of electrical command

Figure 5.Velocities characteristics in the joints and the displacement errors after application the trapezoidal tension command with three constant steps

(under 10% of the relative errors) of the movement trajectory it is possible to use one simple velocity characteristic with three constants values, figure 5; -in many applications where it is necessary a very good precision it is necessary to use some compensation errors methods: classical control cascade consisting of P and PI speed controller; control cascade consisting of P and PI speed controller and the additional band- stop filter and low-pass filter for the speed and the current set values; control cascade consisting of P and PI speed controller by the weighted feed back of the difference of the motor and feed velocity in the angular position control loop; control cascade consisting of a reduced state space controller and PI speed controller; the friction compensation with the injection of an additional current set value or of the equivalent speed set value, in the moment of a starting or reversing movement.
The method is generally, it can be applied in many other mechanical applications.

6. CONCLUSIONS
This method is general. It can be use in all other cinematic error research of the industrial robots. With a good price by using the simple controller is possible to obtain one good precision of the spatial trajectory (under 15% of the relative trajectory errors). These errors can be decreased by apply some control low PD, or PD_2 and with the optimal chose of the according values.

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