5th International Conference
″Computational Mechanics and Virtual Engineering ″
COMEC 2013
24- 25 October 2013, Braşov, Romania

PLANNING THE TRAJECTORY OF THE SCORBOT-ER VII ROBOT

L. Predescu[1], M. Predescu[2]
[1] "Valahia" University, Târgovişte, ROMANIA, e-mail prelaur@yahoo.com
[2] "Valahia" University, Târgovişte, ROMANIA, e-mail zahariamirela@yahoo.com

Abstract: *The paper wishes to analyze the planning and the control of the trajectory of the movement of the end-effector of a rotating robot with 5 degrees of freedom (5R), imposing certain constraints in order to simplify the mathematical approach. By correctly modeling the direct and inverse kinematics, the positions of the end-effector can be determined in terms of time. Simultaneously, constraints can be imposed so that the robot should move on different trajectories within a previously established period of time and the final result would be the precise achievement of the given tasks.*
The illustrated method allows the decoupled calculus of the positioning parameters of the end-effector from the orientation ones. This method simplifies and facilitates the analytical approach of the problem.
Keywords: *robot, kinematic model, trajectory planning*

1. INTRODUCTION

Robotics is usually defined as the science which studies the intelligent connection between perception and action. Referring to this definition, the robotic system is functionally complex, being made up of several subsystems.

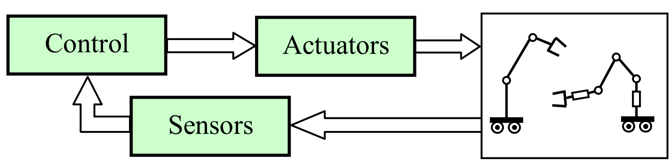

Figure 1 The robotic system components

The mechanical system together with the actuators, sensors as well as the control components make up the robotic system (fig.1). The mechanical system is commonly endowed with a motion apparatus (wheels, crawlers, mechanical legs) and a manipulation component (mechanical arms, end-effectors, artificial hands). In figure 1 the mechanical system is made up of two mechanical arms, either of them being set on a mobile vehicle thus covering as much of the work space as possible and generating its potentially limitless growth.

In terms of base mobility, robots can be:

- Fixed-base robots, also called manipulators;
- Moving-base robots, also called mobile robots.

The mechanical structure of a manipulator is made up of a chain of rigid elements (links), interconnected with different types of articulations (joints).

If this row is disposed in a serial manner to the base, it is called open kinematic chain manipulator, whereas if the links and joints support the task in parallel, it is called closed kinematic chain manipulator.

A manipulator's task is to follow a path in order to lead the end-effector to an established position.

In order to make a robot move along a trajectory between well determined target positions, the movement of different parts of the robot must be established. Consequently, constraints are imposed to reach these positions within a certain time limit, at a certain velocity, acceleration, etc. [1].

Its movement can be achieved through different configurations of its elements, and that is why the robot's movement within the work space must be studied [2], [3].

The kinematic analysis of the robots studies the motion of the composing mechanisms. Everything that has to do with the kinematic analysis, namely position, velocity and acceleration of all the elements will be computed in relation to a reference system which is considered fixed. As far as the kinematic analysis is concerned, the robot's actuating forces and torques are not considered.

In order to follow the functional trajectories, the kinematic model needs a program to generate these trajectories. The program can be either off-line or on-line.

Most of the manipulators are designed to achieve tasks in a 3D work space.

There are two different approaches related to the movement of the robot arm:

- specifying the end-effector's location in 3D coordinates;
- the individual movement of each articulation.

The manipulated part, tool or end-effector has to follow a planned trajectory.

The kinematic model supplies the relations between the position and the orientation of the end-effector and the space positions of the other elements, and articulations.

The kinematic modeling is divided into two problems: direct and inverse kinematics.

The task of direct kinematics is to determine the position and the orientation of the end-effector by giving values to the variables in the robot's joints.

Inverse kinematics focuses on determining the values for the variables in the joints which are necessary to move the robot's end-effector in a desired position and orientation.

2. THE INVERSE GEOMETRIC MODEL

In order to command the robot, the inverse geometric model is used. This model is based on determining generalized coordinates' vector (robot coordinates) $\overline{\Theta} = \overline{\Theta}(q_1, q_2, \ldots, q_k)$ in terms of the operational coordinates' vector ${}^0\overline{X} = {}^0\overline{X}(p_x, p_y, p_z, \alpha, \beta, \gamma)$(the coordinates of the characteristic point P and the angles necessary for the orientation of the end-effector in relation to the system{0}) [4], [5].

The common command algorhythms are made up of relations which express the engine movements in terms of the positioning parameters for the commanded body.

The geometric command modeling (the inverse geometric modeling) has the following vector expression:

$$\overline{\Theta} = f^{-1}\left({}^0\overline{X}\right) \tag{1}$$

It is said that a robot can be solved for a range of tasks involving a ${}^0\overline{X}$ vector of the operational coordinates, if, by knowing the direct geometric model ${}^0\overline{X} = \overline{f}(\overline{\Theta})$, a unique mathematical solution can be obtained for the $\overline{\Theta} = \overline{f}^{-1}\left({}^0\overline{X}\right)$ system.

The connection between the column vectors ${}^0\overline{X}$ and $\overline{\Theta}$ is thus achieved through the *f* operator:

$${}^0\overline{X} = \left[{}^0X_j \,;\, j = 1 \to m\right]^T = \left[f_j\left(q_i \,;\, i = 1 \to n\right);\ j = 1 \to m;\ m \le n\right]^T \tag{2}$$

where m stands for the number of the kinematic parameters and n for the number of the degrees of freedom.

The equations in (2) represent a non linear transcending system of equations for which there is no calculating general algorhythm. Under particular conditions, connected to the relative position and orientation of the neighboring kinematic axes $\overline{k}_{i-1}, \overline{k}_i$, system (2) can be solved using either algebraic methods or methods belonging to the plane geometry. Unlike the geometric approach of the inverse geometric model which differs from one problem to another, the algebraic methods are based on reducing transcending equations to algebraic equation with a single unknown term and consequently they can be generalized. Equation (1) can be written as follows:

$$\left[q_i ; i = 1 \to n\right]^T = \left[f_i^{-1}\left({}^0X_j \,;\, j = 1 \to m\right); i = 1 \to n\right]^T \tag{3}$$

Equations (3) express a certain configuration of the robot which satisfies the known position and orientation of the end-effector.

The great disadvantage of systems (2), (3), is that they are non linear. As we know, such systems can be solved through numerical methods which introduce unavoidable errors.

Any of the solving methods lead to multiple solutions for the generalizing coordinate q_i. Choosing the unique solution depends on the geometry of the mechanical structure of the robot and of its interaction with the environment.

3. THE KINEMATIC MODEL AND PLANNING THE TRAJECTORY OF THE SCORBOT-ER VII ROBOT

The robot used in this project is the **SCORBOT-ER VII** (figure 2). This robot, manufactured by the Israeli company Eshed Robotec Inc.[6], consists of a mechanical arm composed by 5(five) articulations (base, shoulder, elbow and wrist, this last one composed by 2 articulations) and 1 gripper (with 2 stages: open and closed), according to figure 2.

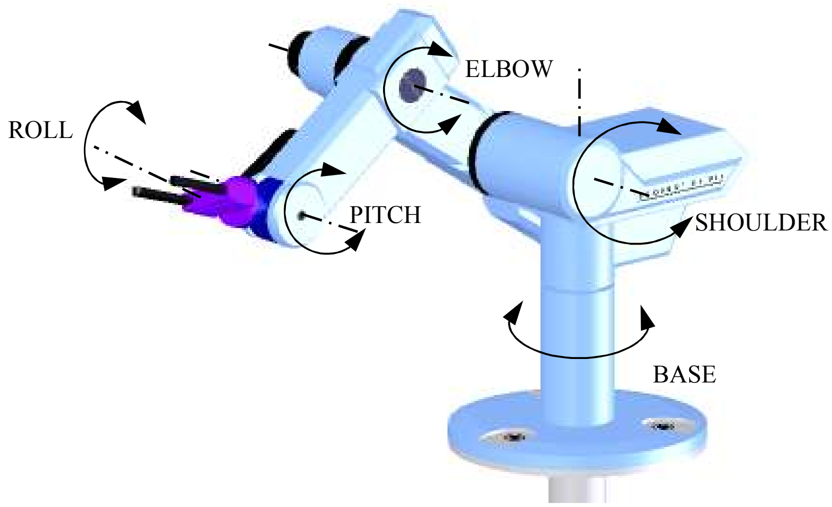

Figure 2 The elements and articulations of the SCORBOT ER VII robot

The kinematic chain in which the chosen reference systems are highlighted is presented in figure 3.

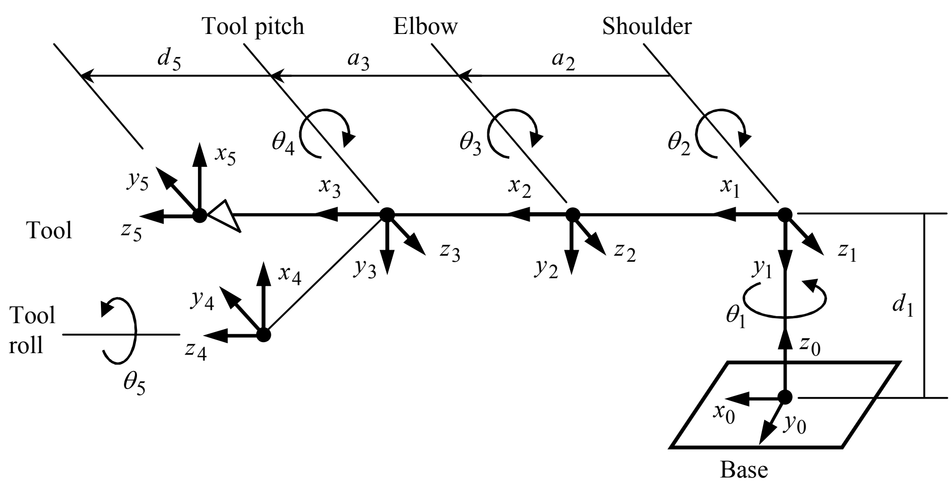

Figure 3 The kinematic chain of the SCORBOT ER VII robot

3.1. Simplified Manipulator Kinematics

Simplified manipulator kinematics has to do with imposing constraints to the kinematic relations. Such a constraint is that the end-effector should be parallel to the base, which results in a simplified model with a simpler solution.

Another simplifying method is the decoupled calculus of the geometric parameters of the robot, by separately analyzing the position equation from the orientation ones.

For a „Pick and Place” operation, the problem of determining a set of variables is considered, namely $\theta_1, \theta_2, \theta_3, \theta_4$, in order to satisfy the demand for position of the end-effector. The demand for orientation of the end-effector (namely θ_5) is neglected.

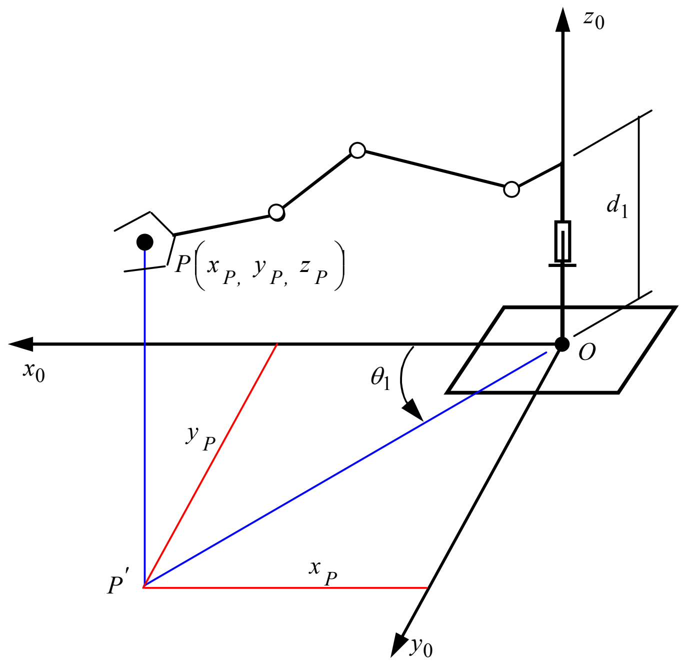

Figure 4 Determining variable θ_1

To calculate variable θ_1 in figure 4 the following formula is used:

$$\theta_1 = a\tan 2\left(y_P, x_P\right) \tag{4}$$

In which the coordinates of point P represented by the values x_P, y_P, z_P as well as the lengths of the robot's elements (a_1, a_2, a_3, d_1 and d_5) are known.

Once θ_1 determined, the problem becomes a plane one, as shown in figure 5.

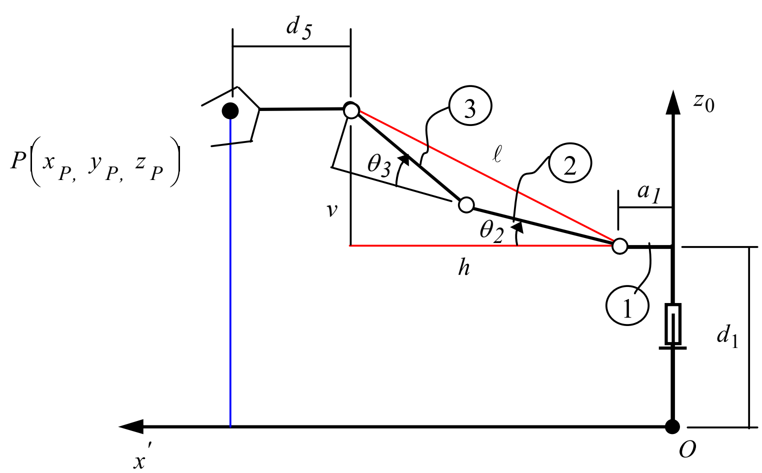

Figure 5 Graphic representation of the SCORBOT ER VII robot

Horizontal distance: $h = \sqrt{x_P^2 + y_P^2} - a_1 - d_5$ (5)

Vertical distance: $v = z_P - d_1$ (6)

$$\ell^2 = h^2 + v^2 \tag{7}$$

$$\ell^2 = a_2^2 + a_3^2 + 2 \cdot a_2 \cdot a_3 \cdot cos(\theta_3) \tag{8}$$

From (7) and (8) results: $\theta_3 = a\,cos\left(\frac{h^2 + v^2 - a_2^2 - a_3^2}{2 \cdot a_2 \cdot a_3}\right)$ (9)

If we annotate with α the angle between ℓ and element 2 (namely a_2) and with β the angle between ℓ and the horizontal h we obtain:

$$\alpha = a\,tan\,2[a_3 \cdot sin(\theta_3), a_2 + a_3 \cdot cos(\theta_3)] \tag{10}$$

$$\beta = a\,tan\,2(v, h) \tag{11}$$

$$\theta_2 = \beta - \alpha = a\,tan\,2(v, h) - a\,tan\,2[a_3 \cdot sin(\theta_3), a_2 + a_3 \cdot cos(\theta_3)] \tag{12}$$

The variable θ_4 was calculated keeping in mind the condition of parallelism between the end-effector and the base:

$\theta_2 + \theta_3 + \theta_4 = 0$ The result is: $\theta_4 = -\theta_2 - \theta_3$ (13)

3.2. Planning the Trajectory

The purpose of planning the trajectory is to generate input data in order to be able to man the movement control system so that the manipulator should execute a trajectory which is established within imposed constraints of velocity and acceleration [7].

A linear trajectory is imposed for the end-effector. It is defined by two points, M and N and the characteristic point P moves along it. The variation within a period of 120 seconds of the angle θ_2 ranging from 0^o to 120^o which means 0 and $\frac{2\pi}{3}$ rad, values which are situated within the functioning limits of the robot [6].

For a set of constant values $a_1 = 0.050\,m, a_2 = 0.300\,m, a_3 = 0.250\,m$, $d_1 = 0.385\,m, d_5 = 0.212\,m$, M(0.785, 0, 0.272), N(0.277, 0, 0.457) and for a sinusoidal variation of θ_2 variations of velocity and acceleration are obtained for point P, as shown in figures 7, and are expressed in $[mm/s]$ and $[mm/s^2]$.

If we refer to a sinusoid variation of the angle which is similar to the one in [8], θ_2 have the structure (14) and the shape in figure 6.

$$\theta_2(t) = A_0 \cdot \frac{\omega_0}{2\pi}\left[t - \frac{1}{\omega_0} sin(\omega_0 \cdot t)\right] \tag{14}$$

For this variation parameter $A_0 = 1\,rad$ and $\omega_0 = 1s^{-1}$ are considered.

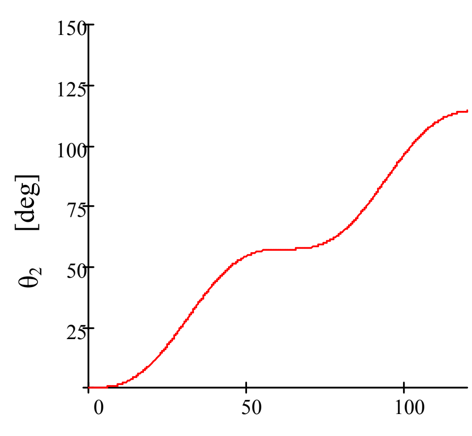

Figure 6 Sinusoid variation in terms of time of the θ_2 parameter.

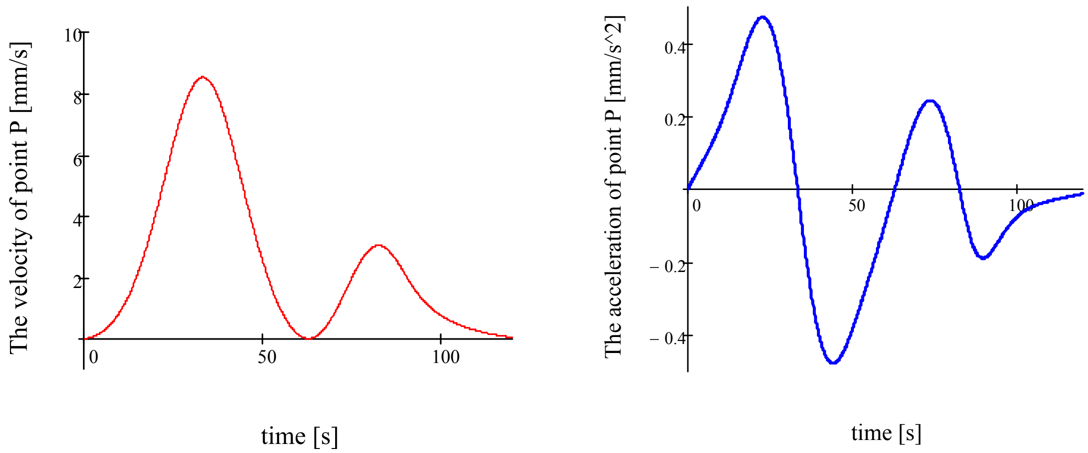

Figure 7 Velocity and acceleration history of point P for the sinusoid variation of the θ_2 angle.

5. CONCLUSIONS

This paper wishes to illustrate the stages of planning and the motion control of a robot with rotary couplers. In order to achieve complex trajectories, we can plan and control the movement, interpolating trajectories belonging to the straight line on a plane.

The method presented here allows the calculation of the geometrical parameters of the decoupled Scorbot-ERVII robot, analyzing separately the position equations and the orientation ones. Even if this procedure simplifies and facilitates the calculation effort, the analytical approach of the kinematic control solutions still remains a complex matter.

The base concept of the proposed approach is constituted by the fact that determining variables involves geometrical modeling of the robotic structure, which leads to multiple solutions, meaning that for a certain positioning, several configurations are obtained in which case it is necessary to intervene in the choice of the variable sets to generate the task.

The comparative study of the graphic representation generates the possibility of an optimal approach to the real work version in terms of the task imposed to the end-effector and its load.

REFERENCES

[1] *B. Siciliano, L. Sciavicco, L.Villani, G. Oriolo,* Robotics Modelling, Planning and Control, Springer, 2009

[2] *J.A. Snyman,* "On non-assembly in the optimal synthesis of serial manipulators performing prescribed tasks"J. Lenarcic and B. Roth (eds.), Advances in Robot Kinematics, Springer, 2006, pp. 349–356

[3] R.N. Jazar, *Theory of Applied Robotics*, 2nd ed., © Springer Science+Business Media, 2010

[4] *P.Popescu, I.Negrean, I.Vuşcan, N.Haiduc, R.Popescu*, Mecanica manipulatoarelor şi roboţilor, Vol.1,2,3 şi 4, Editura Didactică şi Pedagogică R.A., Bucureşti 1994

[5] *V.Filip,* Modelarea manipulatoarelor robot. Calcul simbolic, 1. Geometria directă şi inversă. Cinematica directă, Editura PRINTECH, Bucureşti, 1999

[6] *** User's Manual SCORBOT-ER VII, 2nd ed., Eshed Robotec, 1998

[7] *S.R. Wang, Z.Z. Qiao and P.C. Tung,* "Application of the force control on the working path tracking" Journal of Marine Science and Technology, vol. 10, no. 2, 2002, pp. 98-103

[8] *I. Stroe, S. Staicu, A. Craifaleanu,* "Internal Forces calculus of Compass Robotic Arm Using Lagrange Equations" 11th Symposium on Advanced Space Tehnologies for Robotics and Automation, „ASTRA 2011", ESTEC, Noordwijk, The Nederlands, April 12-14, 2011.