

## Teaching Robotics in a Global point of View

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### ABSTRACT

Robotics is a discipline involving other disciplines like Mathematics and Physics in its base and the most recent research theories in fields like Automation or Control. This is the reason that makes Robotics a discipline of such a large extension of knowledge that it is quite impossible to teach all subjects involved if Universities are not specialized. Since most of the teaching is based on kinematics, differential motion, and occasionally on dynamics, it causes students only to perceive a general and insufficient overview of the whole robotic system. Hence, students will be unable to build up a manipulator and control it after a Robotics term. In this paper, it is presented a global scheme of Robotics as a discipline that can be taught as a complete block diagram going from the trajectory generation to the robot control. The example shown is based in the description by means of Simulink blocks that perform the behavior of a simple  $\theta$ - $r$  trajectory. The schema shows the mathematics involved, the different blocks show in a graphical way the inputs and the correspondent outputs for each stage in robot planning. The main contribution of the paper lies in the fact a new concept of teaching Robotics in a global manner is presented.

### 1. INTRODUCTION

Robotics is one of the most interdisciplinary disciplines taught in Technical Universities as it involves important contents from other disciplines: Mathematics, Physics, Electrical Engineering, Mechanical Engineering and Computer Science. Moreover, considerable

research is done in several fields that Robotics also gathers such as Control, Artificial Intelligence and Vision, and all these fields in a constant evolution. Furthermore, Robotics can be defined Robotics as the intelligent connection of perception to action, decomposing this physical transformation into a sequence of processes: measurement, modeling, perception, planning and action. Hence, Robotics becomes a large discipline and the goal of teaching it in a global manner is difficult to be achieved. This is the reason for many Universities to reduce their teaching to the study of its kinematics, which becomes an incomplete tool to the future engineers who are to be responsible of complex robotics systems in industry.

A robotic system is made up by mechanical structures. In some robot systems these structures must be designed taking into account the loads to be carried as well as the motor that will be chosen in relation to these loads and the whole system structure. The environment where the robot moves and the specific tasks to be carried out will determine the degrees of freedom and degrees of accessibility of the manipulator. Moreover, simple algorithms such as PID or Fuzzy, or even more, by means of techniques of Adaptive Control the robot will be controlled. Fortunately, Mathematics and Physics involved in Robotics are more focused and the bordering disciplines involved are among others: a) Kinematics. The relationship among positions, speeds and accelerations of the links of a manipulator. Frequently, Kinematics is divided into the study of the *transformation matrix* followed by the study of velocities, known as *differential motion*. The Cartesian position and orientation of the end-effector respect to the

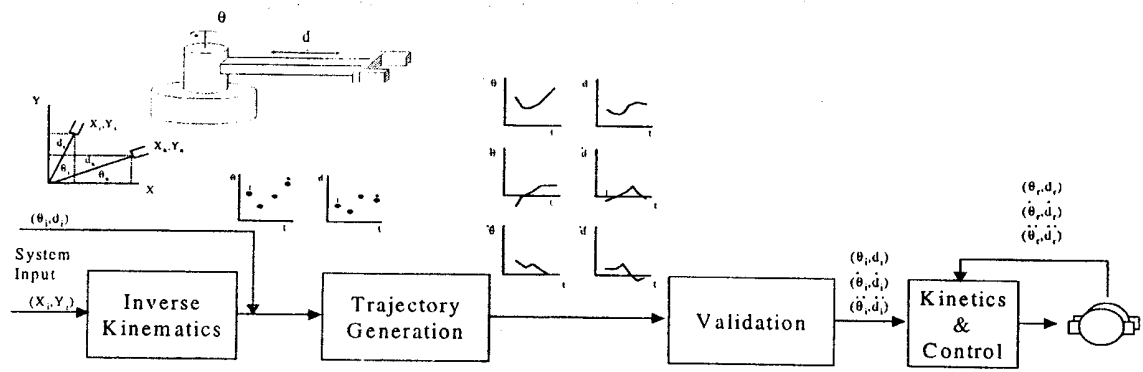


Fig.1 General diagram for the proposed robot system

angular and prismatic position of the joints is studied in detail. Kinematics is interesting to determine the articulated geometry of the manipulator. Its equations define the accessibility of the robot in terms of position and orientation. Then, a trajectory can be defined as a list of points. However, in most cases we will be also interested in fixing the velocity passing through the waypoints. This leads us to imply new subjects; b) Differential Motion, which involves the Cartesian velocities of the end-effector of the manipulator with respect to the joint velocities. Fixing a trajectory will be possible by a sequence of points and attributes of the point that determine the velocity passing through it; c) Statics is another discipline involved in Robotics. In this case the study of the end-effector that puts up with a load. Statics is focused on determining the torques that should be placed in the joints in order to keep the robot in balance (without accelerations). However, the main application of robots finds its place in load carrying so that acceleration is a factor to take into account in order to move the robot. Then, d) Kinetics relates velocities and accelerations of the joints with respect to the forces and torques they exhibit. Finally, e) Control, the manipulator must to be controlled. As far as here we have summarized different aspects of Robotics science but not all.

A lot of books have been published dealing with Robotics [1..9]. The mathematics related to Kinematics, Statics, Kinetics and Control is widely known. However, under our point of view, any of these books can get to show a global approach of Robotics bringing together all the subjects related. Consequently, students often loose the global view of Robotics while their

efforts are put in trying to understand certain details of complex subjects. The proposal of this paper is to present a schema divided into several blocks showing in a graphical way, going from inputs to outputs the whole schema of any robot system containing the stages before mentioned. The main contribution of this paper is to present a new concept of teaching robotics in a global manner. Firstly, the student learns what is a robot system and then what represents each stage of the whole process. The blocks are programmed so as it is possible to see in detail every aspect of a robot system, starting with programming languages and going through trajectory control, kinematics and dynamics, and ending with the manipulator control. To illustrate this new conception for modeling teaching Robotics, it has been used a manipulator  $\theta$ -r as it constitutes an example widely studied in many Robotics textbooks. Out from our experience we can really assure that the interest on Robotics has considerably increased.

In this paper, the general schema is presented and discussed in detail, showing each block, its input and output. The equations have been verified by the use of Matlab and Maple tools, and it has been implemented in Simulink. The model here shown can in the same manner be used to simulate other basic manipulators.

## 1. PRESENTATION OF THE SCHEMA

Figure 1 shows the general schema of the robot system. In order to explain it, we will use the  $\theta$ -r manipulator.

### 1.1 Programming Languages Module

First, we have to consider the programming languages that accomplish the task of interface between the programmer and the robot. A generic language of programming must dispose of the following blocks of instructions: a) *Instructions of positioning and movement control*, b) *Instructions of program control* and c) *Input/Output Instructions*. Furthermore, specific *Instructions of the terminal element*. Here, we can

shown the schema of the module, which is based on the inverse kinematics and the interpolation algorithm. Once the positions have been interpolated, we obtain the outputs shown in Figure 2. Then, Kinematics helps us to transform the Cartesian points to Robot Coordinate points by using the  ${}^R T_H$  matrix. The matrix  ${}^R T_H$  of the manipulator  $\theta$ -r that relates the terminal element with respect to the basis of the robot with respect to the variables of the articulation (direct kinematics), is the following:

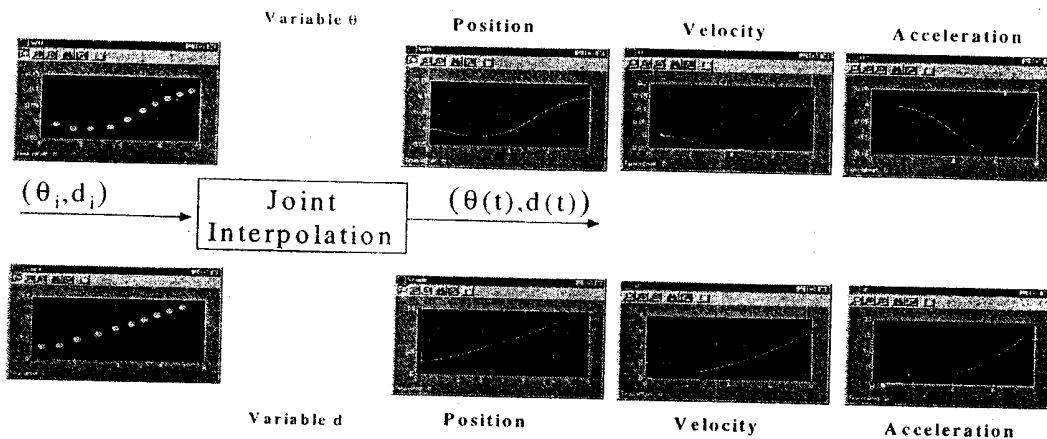


Fig.2 Diagram of the Interpolator Block.

establish a path in Cartesian coordinates and robot coordinates. Moreover, we could decide if we are interested in a lineal path or not. For instance, the instruction *MOVES* executes a lineal Cartesian movement along a given trajectory.

`MOVES[0 -0.3 0.0 -0.8 4.0 15 -1.4 8]`

This instruction causes the robot to start out from the point (X= 0, Y= -0.3) to get to the point (X= 0, Y= -0.8) at t=4s and finish the trajectory at the point (X= 0.15, Y= -1.4) at the instant t=8s. The robot trajectory can be seen in Fig. 2.

### 1.2 Trajectory Generation Module

The points of the path are interpolated in order to execute the desired lineal movement. The block called Trajectory Generation accomplishes this. This controller has been programmed in Simulink making use of an interpolator based on a cubic-polynomial that assures the speed and the acceleration of the manipulator to be continue through the whole trajectory. In Figure 2 it is

$${}^R T_H = \begin{pmatrix} 0 & -c\theta_1 & s\theta_1 & d_2 s\theta_1 \\ 0 & -s\theta_1 & -c\theta_1 & -d_2 c\theta_1 \\ 1 & 0 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

And, being the equations that allow us to obtain the articulation variables in function of the manipulator position (inverse kinematics),

$$\theta_1 = \text{atan2}(p_x, -p_y)$$

$$d_2 = \sqrt{p_x^2 + p_y^2}$$

Once the trajectory points have been converted to robot coordinates points, these must be interpolated once more. The reason of this new interpolation is to obtain a sequence of robot points determining a soft movement that is continuous in velocity and acceleration. Afterwards, the trajectory is sent to the *sequence administrator*. This module controls if the joint motor of the robot can give the velocity and

acceleration for each point. If not, the security control block alerts the user and halts the robot. If the desired velocity and acceleration can be given to achieve the next point position, then, that position is sent to the control module.

the articulation speed) and Coriolis accelerations (depends on the product of the speeds of the articulations

G is a vector containing the independent terms depending on gravity

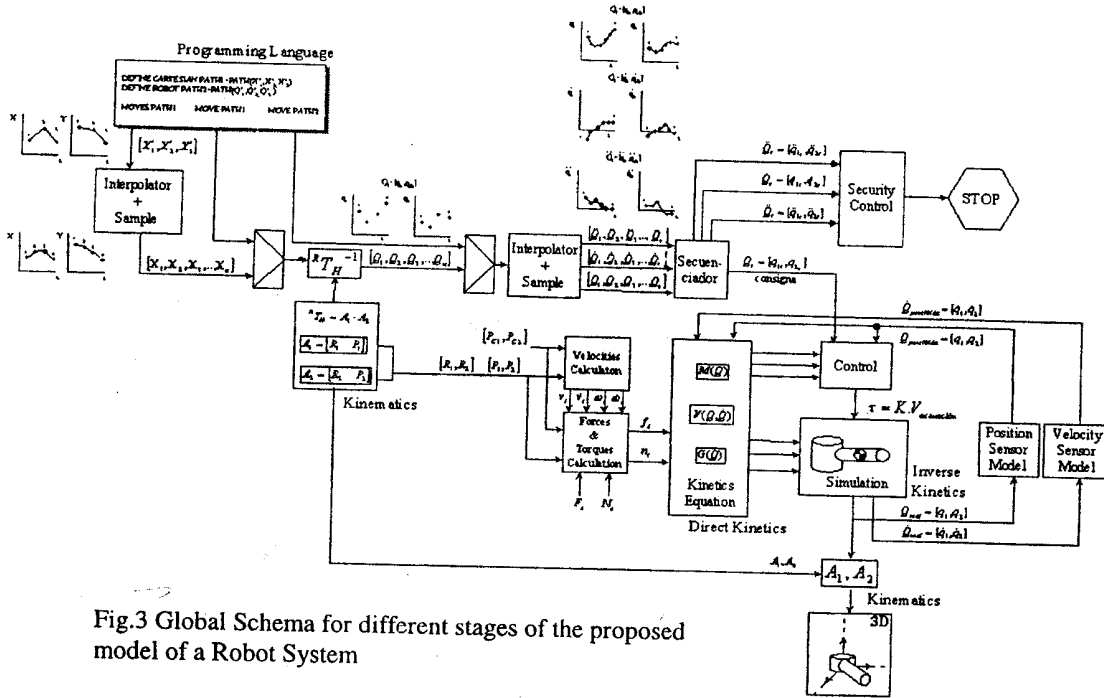


Fig.3 Global Schema for different stages of the proposed model of a Robot System

### 1.3 Dynamics and Control Module

The control module is responsible for the robot motion from the current position to the desired position in a desired time. We can see in Figure 1 how the control algorithm uses Dynamics with the aim to obtain the desired position with the smallest error. The error will be smaller than a control system that does not use dynamics because in dynamics equation the whole structure and the weight of the robot is known. The *joint decoupling* module has been used to simplify the control equations. With that, each motor can be controlled without considering the control of the other articulations. Furthermore, for each point the state equations of dynamics has to be computed:

$$\tau = M(\theta)\ddot{\theta} + V(\dot{\theta}, \theta) + G(\theta)$$

M is known as inertial matrix compound by coefficients that express the resistance of the manipulator to the movement.

V is the vector that contains the terms of centrifuge accelerations ( depends on the square of

In order to achieve the state equations, the lineal and angular velocities and accelerations have to be computed using a recursive algorithm

Furthermore, the achieved velocities and accelerations are used to compute the forces and torques at each link. The equation terms are finally arranged in order to achieve the state equation of the manipulator for the given position Q:

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{4} M_2 d_2^2 + I_{xx2} + I_{yy2} & 0 \\ 0 & \frac{1}{4} M_2 \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{2} M_2 d_2 \dot{\theta}_1 \dot{d}_2 \\ -\frac{1}{4} M_2 d_2 \dot{\theta}_1^2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Finally, the manipulator must be controlled. A simply control can be a positioning control, the voltage given to motors depends exclusively on the error between the actual position and the desired position of the articulation. The torques generated by the actuators depends on the input voltage to the actuator and the model. By means of

the dynamical model is possible to calculate the acceleration of each articulation since a value of voltage is provided. This acceleration value depends on the position and speed of each articulation that are supplied using optical encoders. Accelerations, speeds and positions obtained for the trajectory that is given as example is shown in Figure 3.

It is possible to appreciate the difference between the consign and the real trajectory. In this case, the error is not considerable in the control of prismatic articulation, and a little bit higher in the control of the angular articulation.

At the same time we must dispose of the model of whatever motor that act on the articulations. Given its simplicity, a D.C. motor has been chosen, in this case the model Maxon DC 148867, modeled from the characteristics given by the manufacturer.

Optionally, we can use the  $Q_{real}$  position given by the robot to obtain a 3D representation of the manipulator. Then we need the  $A_i$  matrix of kinematics to accomplish this.

## CONCLUSIONS

This paper presents a global schema with the aim to teach Robotics under the point of view of a subject understood as a global system. Block diagrams and their relationships are a flexible tool to attempt the *robot problem*.

Kinematics, Statics, Kinetics, Simulation and Control are involved in the same schema. All the system is presented in the appearance of a block diagram that by means of simulation the different stages are solved independently. This way to present Robotics has already been successfully tested in our laboratories. The results achieved show that students get a better comprehension of the *robot system*. Comprehension of each module never leaves the whole comprehension. The modules have been simulated using Matlab and Simulink. The system is flexible enough to be used in order to test the behavior of any easy manipulator, as for instance the q-r and the q1-q2 and even 3DOF manipulators. The final paper will show different examples. Out from our experience the presented system might be quite interesting and useful to scientific and pedagogic task that is being carried out in many Universities all over the world with the aim to teach Robotics with a global point of view.

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