Technological Development and Implementation of a Robotic Arm Motioned by Programmable Logic Controller

J. G. Batista, L. J. de Bessa Neto, M. A. F. B. Lima, J. R. Leite, J. I. de Andrade Nunes

Abstract—The robot manipulator is an equipment that stands out for two reasons: Firstly because of its characteristics of movement and reprogramming, resembling the arm; secondly, by adding several areas of knowledge of science and engineering. The present work shows the development of the prototype of a robotic manipulator driven by a Programmable Logic Controller (PLC), having two degrees of freedom, which allows the movement and displacement of mechanical parts, tools, and objects in general of small size, through an electronic system. The aim is to study direct and inverse kinematics of the robotic manipulator to describe the translation and rotation between two adjacent links of the robot through the Denavit-Hartenberg parameters. Currently, due to the many resources that microcomputer systems offer us, robotics is going through a period of continuous growth that will allow, in a short time, the development of intelligent robots with the capacity to perform operations that require flexibility, speed and precision.

Keywords—Direct and inverse kinematics, Denavit-Hartenberg, microcontrollers, robotic manipulator.

I. INTRODUCTION

THE industrial robotics is a branch of technology that englobes mechanics, electronics, and computing, which currently deals with automated systems and controlled by integrated circuits, making mechanical systems automated [1]. Due to its complexity, robotics has presented many challenges for engineering. This is reflected in the industry in the fact that only a few countries develop robotic systems. Countries such as Brazil still cannot manufacture the entire robotic system, they only assemble parts from countries that manufacture industrial robotic systems; mainly, Germany, Japan, and the United States of America [2].

An industrial robot can be defined as an articulated mechanical system whose main objective is to perform predefined operations that are realised through a control supervisor who must specify the tasks specified [3].

An industrial robot is usually constituted of six degrees of freedom, and the positioning of its terminal element (operating tool) is specified through the control so that its joint variables determine the positioning of its terminal element in the

working coordinate system. In general, the first three degrees of freedom of a robot are responsible for the positioning of its terminal element in the task space, and the remaining ones by the use as a tool for orientation [4]. Fig. 1 illustrates two alternative possibilities for defining the zero-initial coordinate system of a PUMA type manipulator with six degrees of freedom: six joints, six movable links plus a base or zero link. It should be noted that there would still be several other possibilities of choosing the systems.
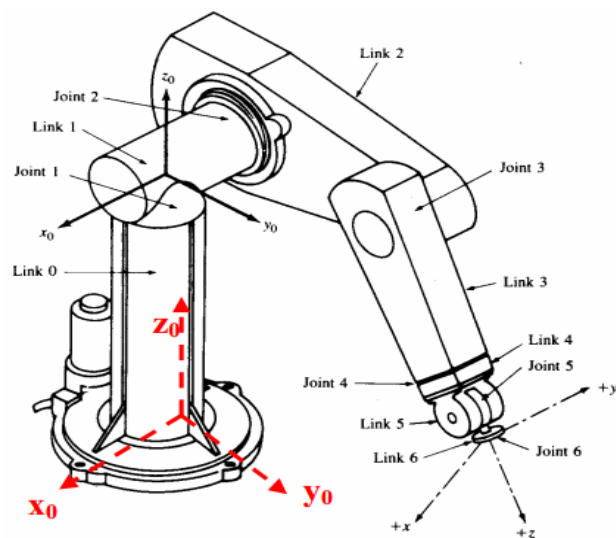

Fig. 1 Links and joints of a type manipulator PUMA 560. Adapted of [4]

A robotic system basically consists of three parts: the electromechanical arm, the digital controller, and a programming language. The first consists of electric, hydraulic, or pneumatic drive with direct and indirect couplings, e.g. gears, pulleys, and toothed belts [10]. It also includes mechanical protections and fairing of the robot. This is generally made of aluminum or cast iron [5].

The controller consists of drivers for control of the motors, power system, and computer system for storage and data processing for robot operation [10]. The system has still inputs and outputs of digital and analog signals for controlling external devices such as feeders, mats and automatic actuator exchange [6]. Therefore, the functions of the robot controller are the generation of trajectories from the coordinates

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provided by the operator and the control of the execution of the trajectory generated.

II. KINEMATICS OF MANIPULATORS

A. Kinematics of an Industrial Robot

The kinematics of a robot study the movement of robots in relation to a reference of system. Therefore, the kinematics deals with the analytical description of the robot's spatial motion as a function of time, and in particular the relations between the position and orientation of the robot's tool with the values that make its coordinates articulate [7]. The problem of direct kinematics consists in determining the position and orientation of the manipulator actuator in relation to a fixed reference coordinate system known as the values of the joints; the inverse kinematics problem solves the configuration that the robot must adopt to a position and orientation of the known extreme [2].

B. Control of Kinematics of Industrial Robot

The fundamental objective of the two models is to be able to establish the appropriate strategies of control of the robot that result in greater quality of its movements [8]. Taking into account the variety and complexity of the structures that make up manipulator robots, kinematics describes the relative movement of the various reference systems as the structure moves, associating reference systems with the various parts of the structure [2].
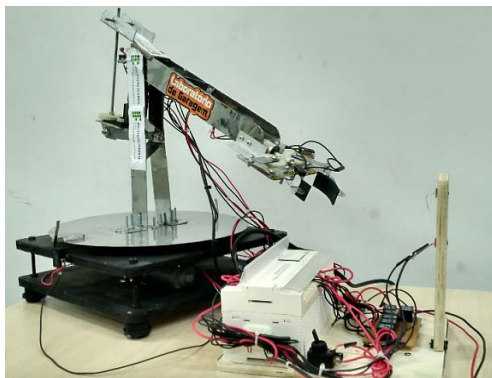

Fig. 2 Robotic arm motioned by PLC. IFCE, 2016

The kinematic control establishes which trajectories are to be followed by each robot articulation in a time interval to reach the goals set by the user (target point, Cartesian trajectory of the robot tool, time spent by the user, etc.) [9]. These trajectories are selected according to the physical constraints of the drives and to certain quality criteria of the trajectory, such as smoothness or accuracy [2].

This work presents the mathematical modeling of a manipulator robot with two degrees of freedom for the displacement of small and medium mechanical parts in industrial processes. The modeling includes kinematics (direct and inverse). Fig. 2 shows the robotic arm by which this work is referenced. The robot was kept by the authors in the Manufacturing Technology Laboratory of the Federal Institute of Education, Science and Technology of Ceará – IFCE *campus* Tabuleiro do Norte.

III. MATERIAL AND METHODS

In order to develop its own technology, based on manipulator robotics, aiming to optimize the speed and precision of transport and displacement of mechanical parts in industrial automation processes, small and medium postage of materials was used for the elaboration of a robotic arm of two degrees of freedom, aiming to demonstrate its efficiency in industrial applications.

For the construction of the robotic manipulator, it was tried to use recyclable materials, like two quadrangular woods of dimensions (30 cm x 30 cm) for the base, four rollers for the damping of the movements of the robot, stainless steel plates of dimension (27 cm x 4 cm) for the mechanical structure of the manipulator, 3 m of flexible electric cables of different colors of 2.5 mm², six ends of travel sensors, three engines of continuous current 12V, six electromechanical relays with a nominal voltage of 12V, for which they are responsible for reversing the direction of rotation of the engines, through a combinational logic of contact switching, in addition to a Programmable Logic Controller (PLC), whose function is to command the robotic arm in the execution of its tasks. Table I shows the components of listing.

TABLE I
COMPONENTS USED TO THE ELABORATION OF ROBOT

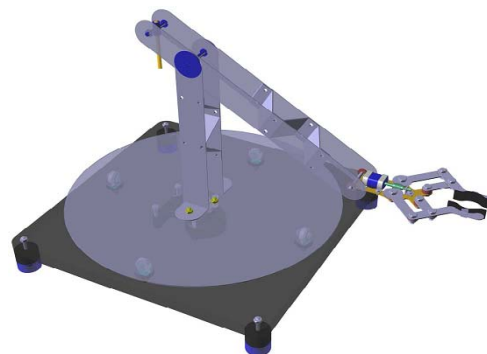| Robotic Manipulator		
Components	Amount	Price (R$)
Stainless steel	3 m	30.00
Electrical Cables (2.5 mm²)	3 m	20.00
Wood	0.6 m	0.00
End of travel sensors	6	10.00
Engines DC 12V	3	10.00
Electromechanical Relays 12V	6	36.00
Rollers	4	20.00

Fig. 3 Mechanical structure of the robotic arm. IFCE, 2016

The robotic arm developed for this work is an industrial manipulator capable of performing tasks that require agility, precision, and repeatability. With the objective of obtaining relevant information from the robotic manipulator, a computational modeling of the robot in the Rhinoceros 3D

software was done, as shown in Fig. 3, where the actual dimensions and the constituent material of the manipulator are observed, being stainless steel, rubber and wood.

Aiming to minimize the costs of construction of the robotic manipulator, engines of continuous current 12V were used for a movement of the robot joint joints. In order to reverse the direction of rotation, as well as precisely control their speed, a combinational logic of electromechanical relays has been

developed in Proteus Professional software, as shown in Fig. 4. The electronic circuit symbolizes basically the supply of the relays coils by a 12V of battery, the connections combinational logical of contact switching (NA-NF) between the relays, the digital outputs of the PLC that have been defined in the programming code in *Ladder*, which represent the hourly and anti-clockwise rotation of the engines (horizontal, vertical and claw).
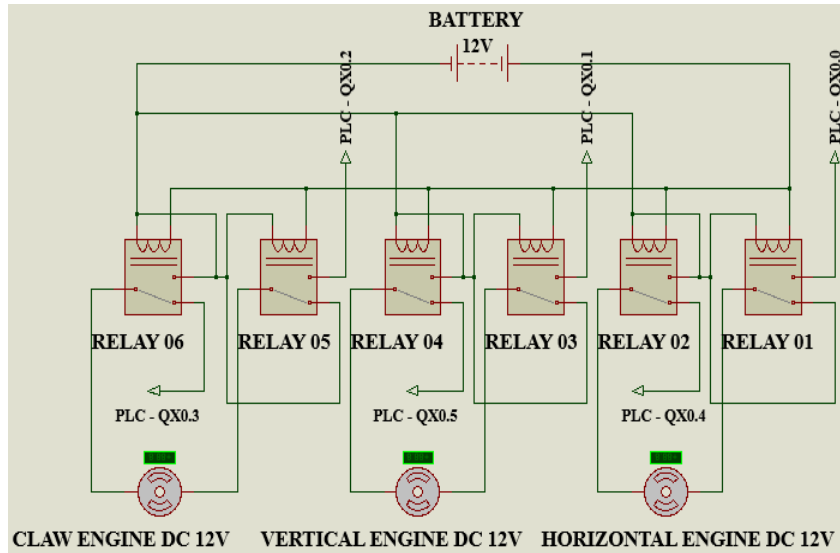

Fig. 4 Electronic circuit of the board of electromechanical relays. IFCE, 2016

IV. RESULTS AND DISCUSSION

A. Direct Kinematics

The equations of the direct kinematics of the Robotic Arm were found from the allocation of the reference systems, represented in Fig. 5, and application of the Denavit - Hartenberg parameters, as described in Table II. In this way, the transformation matrices of the joints were obtained, and then, the homogeneous transformation matrix, as seen in (1), was calculated, which indicates the location of the robot end element, the tool, in relation to the fixed inertial reference system of the base.

TABLE II
DETERMINATION OF THE PARAMETERS OF DENAVIT-HARTENBERG

Link	Parameters D-H			
	Angles of Joints	Angle of Link twist	Length of the link	Displacement of the joint
1	θ_1	$+90°$	0	L_1
2	θ_2	$0°$	L_2	0

$$\begin{bmatrix} C_1C_2 & -C_1S_2 & S_1 & L_2C_1C_2 \\ S_1C_2 & -S_1S_2 & -C_1 & L_2S_1C_2 \\ S_2 & C_2 & 0 & L_2S_2+C_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$
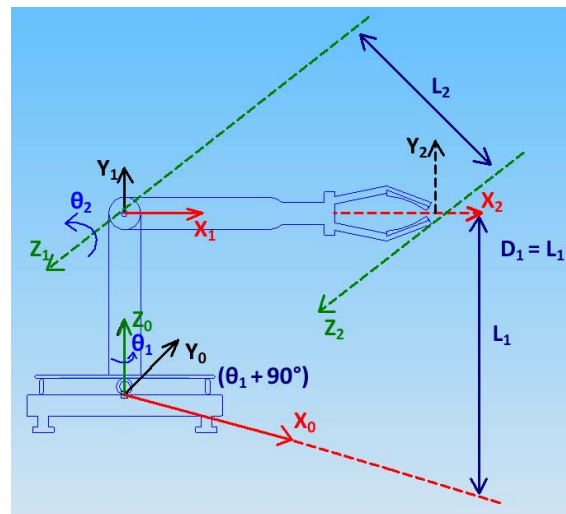

Fig. 5 Systems of references coordinates

B. Inverse Kinematics

Based on the homogeneous transformation matrix of the direct kinematics, to solve the problem of inverse kinematics, the matrix expression of the robotic manipulator seen in (2) was determined by which the individual expressions of the joints of the robot seen in (3) were developed finding the parameters exemplified in (4) and (5).

$$^{R}T_{H} = A_1 A_2 \ldots A_n \tag{2}$$

$$^{R}T_{H} \cdot A_n = A_1 A_2 \ldots A_{n-1};$$

$$^{R}T_{H} \cdot A_n^{-1} \cdot A_{n-1}^{-1} = A_1 A_2 \ldots A_{n-2}; \tag{3}$$

$$\theta_1 = \arctan \frac{p_y}{p_x} \tag{4}$$

$$\theta_2 = \arctan \frac{p_z - L_1}{p_x C_1 + p_y S_1} \tag{5}$$

V. Conclusions

It can be extracted, as the main conclusion of this work, that the study of the kinematics of a robotic manipulator is essential to optimize its efficiency and precision in industrial activities, besides being necessary for the generation of trajectories of the manipulator.

The purpose of this study was successful, which is the modeling of the kinematics (direct and inverse) of the robot, which is not a simple task, since there may be several solutions to the inverse kinematics and it demands a lot of time and high computational performance to execute them.

It is the intention of the researchers of this article, in future works, to carry out the study of differential kinematics and dynamics of the robotic arm, as well as perform the simulation and execution of the trajectory generation thereof.

Acknowledgment

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