Case Studies in Mechanical Systems and Signal Processing 3 (2016) 9–21

Contents lists available at ScienceDirect

Case Studies in Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/csmssp

# Design, simulation and comparison of controllers for a redundant robot

Claudio Urrea*, John Kern

*Grupo de Automática, Departamento de Ingeniería Eléctrica, Universidad de Santiago de Chile, Chile*

ARTICLE INFO

*Article history:*
Received 15 September 2015
Received in revised form 18 November 2015
Accepted 9 December 2015
Available online 22 December 2015

*Keywords:*
Controllers
Robots
Redundant manipulators
Dynamic model
Simulation

ABSTRACT

The simulation tools are the foundation for the design of robot systems, for the application of robots in complex environments and for the development of new control strategies and algorithms. Because of this, the design, simulation and comparison of the performance of controllers applied to a redundant robot with five degrees of freedom (DOF) are presented in this paper. Through homogeneous transformation matrices the inverse kinematic model of the redundant robot is obtained. Six controllers are prepared to test the robot's dynamic model: hyperbolic sine–cosine; computed torque; sliding hyperbolic mode; control with learning; and adaptive. A simulation environment is developed by means of the MatLab/Simulink software, which allows analyzing the dynamic performance of the robot and of the designed controllers. This simulation environment is used to carry out different tests of the redundant manipulator model together with each controller as they are made to follow a trajectory in space. The results, obtained through a simulation environment, are represented by comparative curves and RMS indices of the joint and Cartesian errors, and they show that the redundant manipulator model follows the test trajectory with less pronounced maximum errors using the adaptive controller than the other controllers, with more homogeneous motions of the manipulator. The largest joint and Cartesian errors generated when testing the robot model, both in terms of maximum and RMS values, occurred when the computed torque controller is used. The results with that controller are obtained by executing three iterations for learning, because with more iterations the variations were not important.

## 1. Introduction

The use of industrial robots, since its beginnings more than 60 years ago, has made it possible to increase productivity and improve the quality of manufactured products, becoming massified and extending rapidly to various fields of application such as the automotive, plastics, food, lumber, agricultural, aeronautics, railways, energy industries, and the aerospace industry (National Aeronautics and Space Administration: Curiosity in 2012), among others [1,2]. This extensive range of applications has therefore required flexibilizing the work space of the robots, a characteristic that can be achieved by increasing their degrees of freedom, i.e., providing them with redundancy. However, all these activities would not be possible without an adequate design of the robot and of its technical control. Fulfilling this requires the knowledge and study of a mathematical model and of a certain class of "intelligence" that can direct the manipulator to perform the assigned tasks.

---

* Corresponding author at: Departamento de Ingeniería, Eléctrica Universidad de Santiago de Chile, Av. Ecuador, 3519, Estación Central Santiago, Chile.
*E-mail address:* claudio.urrea@usach.cl (C. Urrea).

http://dx.doi.org/10.1016/j.csmssp.2015.12.001

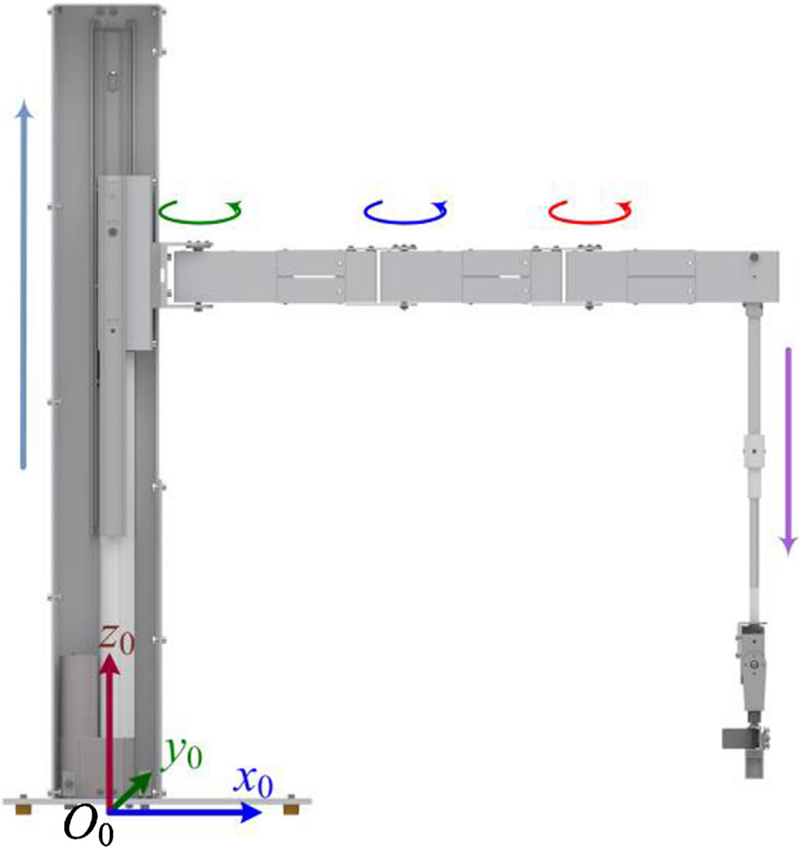

**Fig. 1.** Scheme of a robotized manipulator with rotational and prismatic redundance.

Using the basic laws of physics that govern the robot's dynamics, it is possible to derive a mathematical model that represents its behavior, and through appropriate programming tools, develop an environmental simulation to subject it to different tests such as, for example, following trajectories [3–7]. Because the simulation tools are the foundation for the design of robot systems, for the application of robots in complex environments and for the development of new control strategies and algorithms, this paper takes up the modeling and control of a redundant robot with five DOF that is tested by making it follow a test trajectory composed of a spiral in Cartesian space. Six controllers are made to test the model: hyperbolic sine–cosine; computed torque; sliding hyperbolic mode; control with learning; and adaptive. A simulator is developed by means of MatLab/Simulink software on which the redundant robot model is executed together with each controller. This analysis also includes the dynamics of the actuators. The results are shown by means of comparative curves and RMS indices of the joint and Cartesian errors.

## 2. Redundant robots

Redundant robots are those that have more degrees of freedom than those required to perform a given task [8–11]. In recent years special attention has been given to the study of redundant manipulators, and this redundancy has been considered as an important characteristic in the performance of tasks that require dexterity comparable to that of the human arm, such as, for example, in the space mission called *Mars Science Laboratory* (MSL), better known as *Curiosity*. Although most redundant manipulators do not have a sufficient number of degrees of freedom to carry out their main tasks, e.g., following the position and/or the orientation, it is known that its restricted manipulability results in a reduction of the work space[1] due to the mechanical limitations of the joints and to the presence of obstacles in that space. This has led researchers to study the performance of the manipulators when more degrees of freedom are added (kinematic redundancy), allowing them to fulfill additional tasks defined by the user. Those tasks can be represented as kinematic functions, including not only the functions of kinematics that reflect some desirable properties of the manipulator's performance such as the characteristics of the joints and the evasion of obstacles, but can also be expanded to include measurements of the dynamic

---

[1] Region of space where the manipulator can position its terminal effector (end of its wrist), that is determined by the robot's geometric configuration.