Dynamics of a 6R industrial robot

M Ratiu[1], A Rus[1] and M L Balas[2]

[1] Department of Mechanical Engineering and Automotive, University of Oradea, 410087 Oradea, Romania
[2] Department of Product Design, Mechatronics and Environment, Transilvania University of Brasov, 500068 Brasov, Romania

E-mail: mratiu@uoradea.ro

Abstract. In the context in which, the dynamic behavior and performance of industrial robots are very important for their general performance, we present, in this article, a short dynamic analysis of an industrial robot. First, on the base of a short review of some papers on this topic, a general presentation of some main concepts regarding the dynamics of the industrial robots, and of the actual importance of the virtual prototyping in studying the dynamic behavior and performance of such complex mechanical systems are highlighted. How the modern virtual prototyping tools allow better, more rapid, and less costly dynamic designing of the complex mechanical systems, comparing to the traditional designing and prototyping, and ADAMS MBS of MSC software enables the evaluation of the dynamic behavior of the virtual prototype of a robot during its designing stage, by starting from the kinematic model previously developed, we conducted in this research the process of dynamic modeling and simulation of a 6R articulated robot developed in ADAMS and a short dynamical analysis of it.

1. Introduction

In the last decades, in the context of using, on an increasing scale, and in more and more numerous and diverse fields, of the robots, as well as of the development, in an accelerated rhythm, of the computer-based designing techniques, the virtual prototyping has become much more used compared to the physical prototypes. Having advantages such as reducing the execution time or lowering costs, the possibility of simulation and testing in different stages or alternatives, there are, today, several complex software packages and a lot of studies on the modeling and virtual prototyping of the industrial robots, as presented in [1].

In robots' dynamics, virtual prototyping is an important and ordinary tool used nowadays by several simulating software, ADAMS being declared, in [2], the most known one. Also, in a survey based on the user feedback and presented in [3], the participants indicated more tools currently used by them for the dynamic simulation of the robots, the most known tool being ADAMS (45%). According to these findings, and after a short literature review on this topic, we found that ADAMS software is considered one of the best solutions for analyzing the dynamic behavior of complex mechanical systems, and an efficient alternative to the numerical simulation of the dynamic behavior of industrial robots.

In our research, by using the MBS (Multi-Body System) software ADAMS (Automatic Dynamic Analysis of Mechanical Systems), we developed, in [4], a virtual kinematic model of a 6R articulated robot, with six revolute joints, and conducted, in [5] a short kinematic analysis for it, through direct and inverse kinematics.

In this paper, after a general presentation of some main concepts regarding the dynamics of the robots, by starting from the kinematic model of the robot, developed before, we present the process of dynamic modeling and simulation of the robot, in ADAMS/View, according to [6], [7] and [8].

2. Dynamics of the industrial robots

The dynamic analysis of the multibody systems describes, through the dynamic equations of motion, the relationship between the forces acting on the system and the motion produced by them. The dynamics of robots are important for their design, simulation, and control [9, 10]. There are several parallel algorithms used for dynamic calculation of industrial robots and several approaches, most using either Lagrange or Newton-Euler formalism.

The dynamical analysis is, generally, both direct and inverse. In the direct or forward dynamics, the torques or forces applied to the actuators are specified and the accelerations of the joints are determined, this kind of analysis being required for simulation. In the inverse dynamics, starting from the specification of the robot's trajectory (position, speed, and acceleration), the torques or forces required for the actuators are determined, this type of analysis being used for data control and trajectory planning. There is, in addition, the third type of computation, namely hybrid dynamics, in which some of the accelerations and forces are given and it is necessary to determine the rest of them [11].

In the dynamic analysis are used, also, other two types of computations, namely the joint-space inertia matrix, which leads to the accelerations and the torques or forces in the joints and it is, as a rule, an integral part of many direct dynamics formulations and the operational-space inertia matrix, which leads to the accelerations and forces developed to perform the task, in the operational or Cartesian space, and it is used to control the end effector or the execution level of the robot load [12].

3. The dynamic model of the robot

The dynamic model of a robot expresses the relationship between the torques and/or forces applied to the actuators and the positions, speeds and articular accelerations. In developing the dynamic model of a robot, several criteria have to be considered, cumulatively, the most important being the need to travel the trajectories as accurately and as quickly as possible; the other criteria refer to the need for real-time operation, the need to minimize the effect of the interconnection between the elements of the guiding device, the ability to compensate for the mass variations of the manipulated object, to ensure the robot's robustness.

The virtual dynamic model of the robot is very useful and necessary for simulating its motion, thus not needing the construction of a real model. The dynamic model contains information about the mass and inertial properties of the component parts of the robot's mechanical system. The dynamic model of the robot also provides the information needed to analyze the dynamic behavior of the mechanical system of the robot.

A valid model, that represents the kinematic and dynamic properties of a robot, helps to understand the reciprocal relationships between the tasks applied in each joint and the resulting motion of the robot. Based on the dynamic model of the robot, various driving models can be made.

By using ADAMS, virtual prototypes of some different industrial robots were developed and used for dynamic simulation or verification of the numerical models established in SolidWorks [13], MATLAB [14, 15, 16, 17] or MATLAB and Maple [18]. The common conclusion of all these papers is that the results of the dynamic simulations developed in ADAMS are in agreement with the numerical results of the theoretical models, and, according to [19], represents a better alternative.

The capabilities of the MBS software, namely ADAMS, in the analysis and testing of the complex mechanical systems are demonstrated in another paper, [20], by using three types of virtual mechanical models, the same as in [21]:

- the kinematic model, that contains the kinematic elements (bodies) of the robot, connected by the kinematic joints, and the geometrical parameters specific to the mechanism (the locations of the joints);

the entry is made by using the kinematic restrictions (the motion generators), through which the position or speed of the driving elements is controlled;
- the inverse dynamic model, that includes the kinematic model and the external and internal forces acting on the system, including the massic-inertial characteristics, this model being used to determine the motor torque / motor force that generate the kinematically prescribed motion of the mechanism;
- the dynamic model, which includes the inverse dynamic model, the input being made by the motor torque / motor force, its purpose being to evaluate the behavior of the mechanism under the action of the forces.

4. Dynamic simulation in ADAMS

By following a so-called master-slave approach, for the kinematic and dynamic analysis of the robot, as proposed in [22], and developed in [5], was obtained the dynamic model of the robot, presented in figure 1, necessary for the investigation of the robot' dynamic behavior.

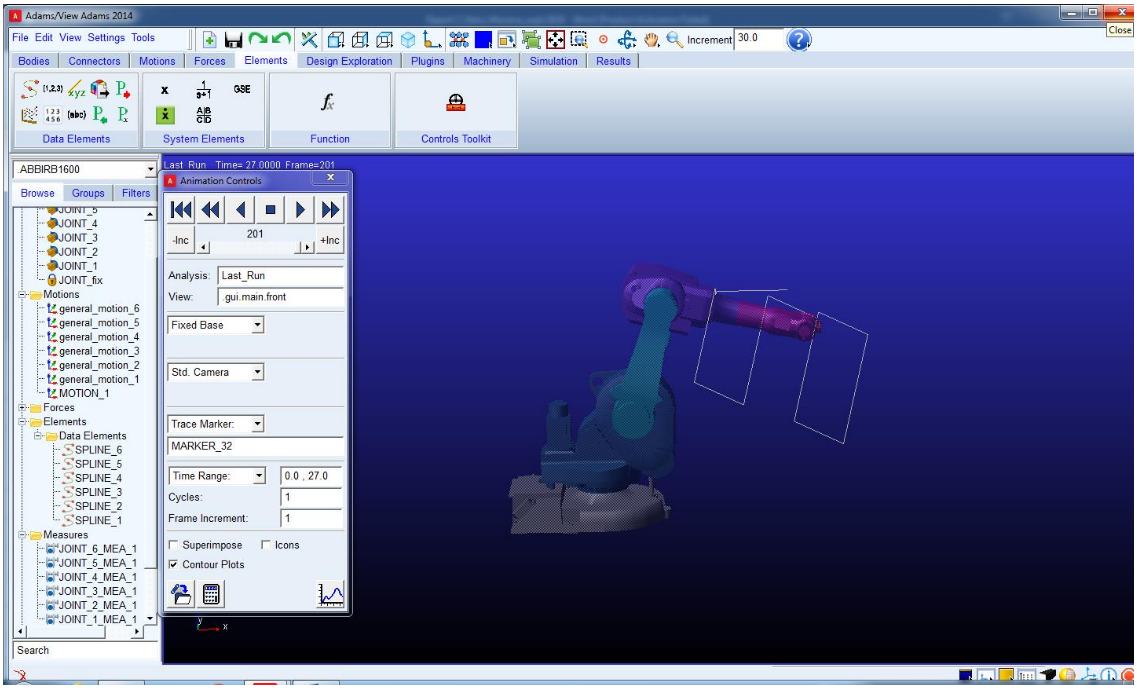

Figure 1. Dynamic model of the robot in ADAMS.

By choosing, in the process of virtual simulation, the aluminum as the material from which the robot is built, with density 2740 kg / m^3 and Young module 71705 newton / mm^2, were obtained the mass and inertia properties of the robot bodies, presented in Table 1.

Table 1. Mass and inertia of the robot bodies.

Link	Mass, m [Kg]	Principal moments of inertia [Kg · m^2]		
		I_{xx}	I_{yy}	I_{zz}
Body 1 - Base	79.03	$3.43 \cdot 10^6$	$2.30 \cdot 10^6$	$1.33 \cdot 10^6$
Body 2	109.42	$3.80 \cdot 10^6$	$3.21 \cdot 10^6$	$1.67 \cdot 10^6$
Body 3	21.67	$7.49 \cdot 10^5$	$7.30 \cdot 10^5$	$5.22 \cdot 10^4$
Body 4	44.82	$7.40 \cdot 10^5$	$6.93 \cdot 10^5$	$3.14 \cdot 10^5$
Body 5	7.91	$7.50 \cdot 10^4$	$7.25 \cdot 10^4$	$1.30 \cdot 10^4$
Body 6	0.49	411.71	324.35	264.41
Body 7 - End effector	0.088	39.42	39.10	17.03

For an animation of the robot motion, for 27 s and 200 steps, with the end effector following a spatial trajectory, as presented in figure 1, the variation of the kinetic energy of the mobile elements of the robot is shown in figure 2 and the variation of the potential energy in figure 3.

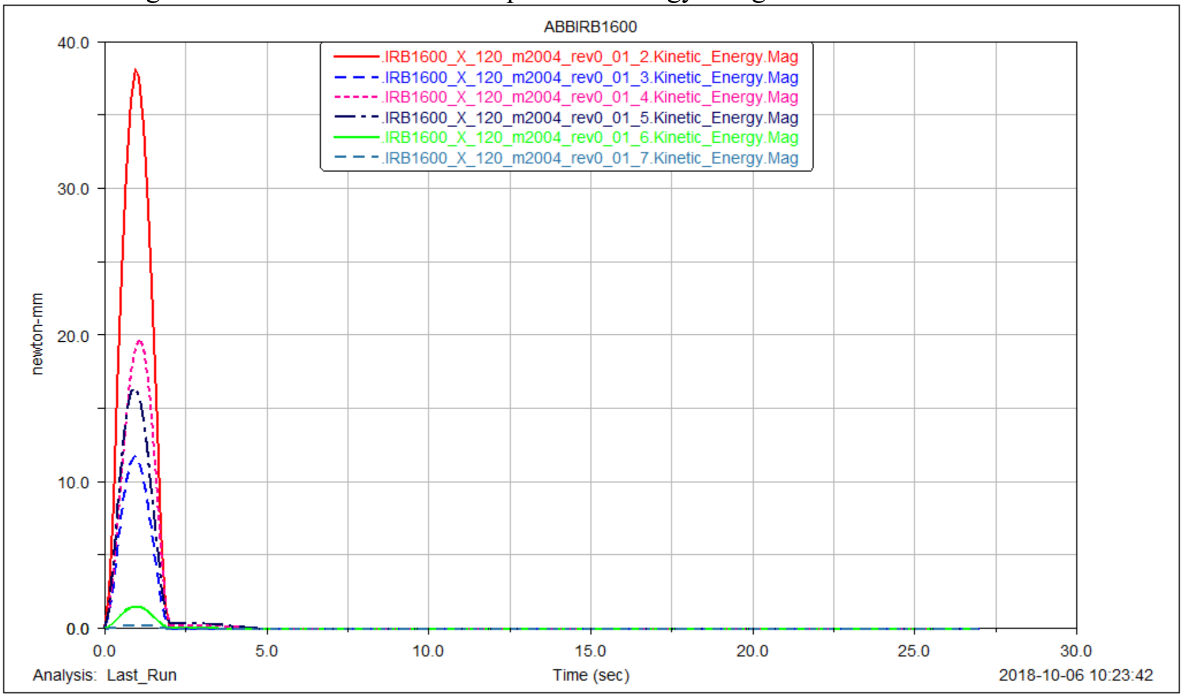

Figure 2. Variation of the kinetic energy of the mobile elements of the robot.

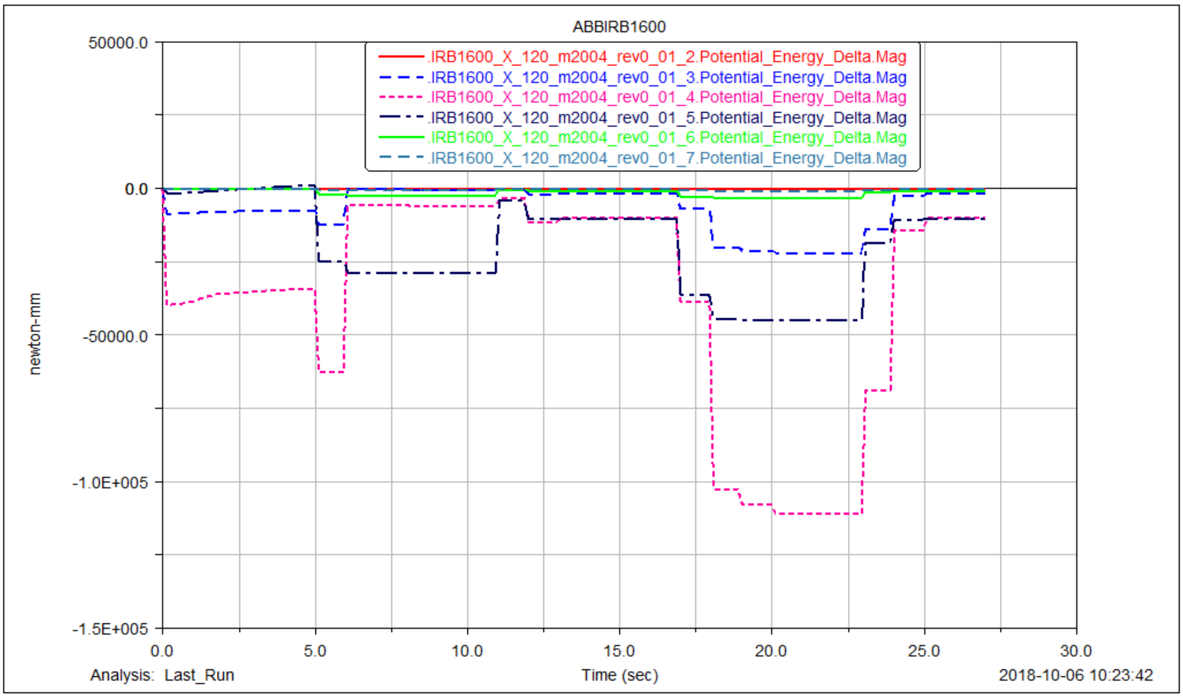

Figure 3. Variation of the potential energy of the mobile elements of the robot.

The variation of forces and torques in the robot joints are presented in figure 4, respectively 5, and they could be used for studying the joints behavior, by using finite element analysis, in future work.

How, normally, the force and torque exerted in a joint due to gravity are in a function to the robot pose, in this case, the bigger values are registered for the first joint, when the robot arm is in the closest pose to the horizontal.

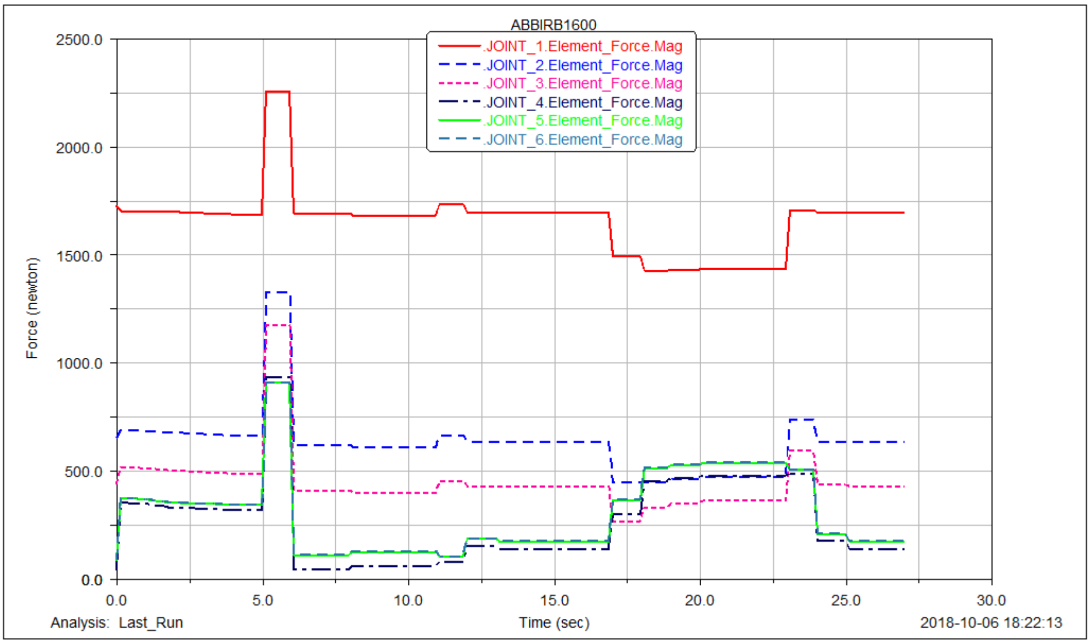

Figure 4. Variation of forces in robot joints.

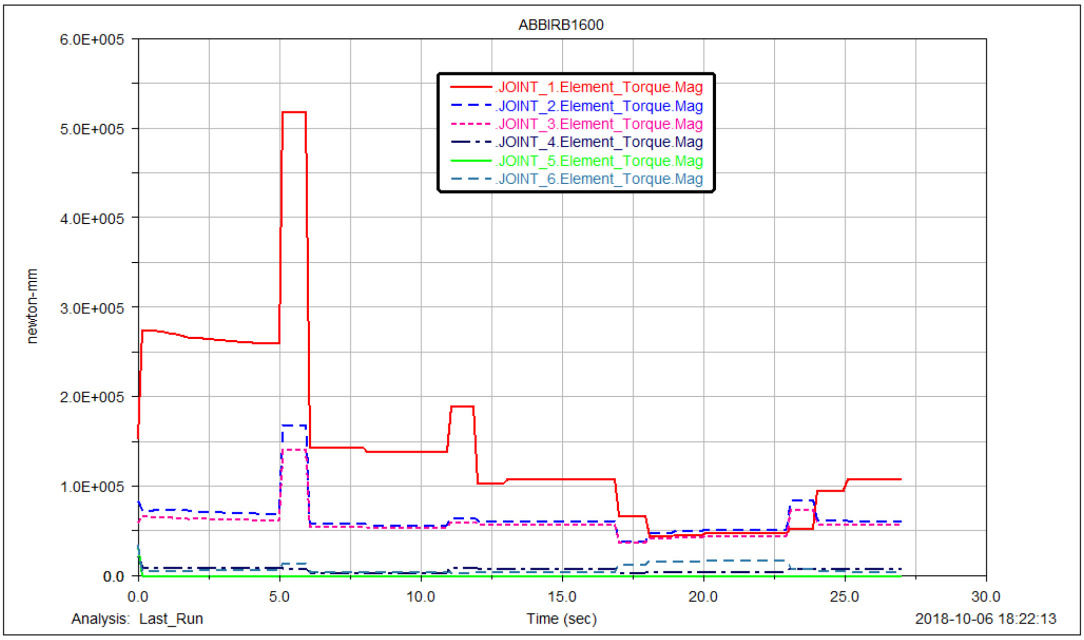

Figure 5. Variation of torques in robot joints.

5. Conclusion

The dynamic behavior and performance of industrial robots are very important for their general performance. The modern virtual prototyping tools allow better, more rapid, and less costly dynamic designing of the complex mechanical systems, comparing to the traditional designing and prototyping.

After a short literature review on this topic, we found that ADAMS enables the evaluation of the dynamic behavior of the virtual prototype of a robot during its designing stage, in much less time and at a lower cost, before realizing the experimental prototype. By adding other opportunities, such as the possibilities to increase the operation speed and maintain the precision of positioning, to avoid the vibration, to validate and optimize the control algorithm, and to evaluate the ability of the virtual model to perform a wide range of applications, Adams offers the possibility to create a better robot in a shorter period.

According to these findings, by using ADAMS in our researches, we developed a virtual kinematic and dynamic model of a 6R articulated robot and conducted a short kinematic and dynamic analysis for it. In this paper, we present the variation of the kinetic and potential energy of the mobile elements of the robot, and, also, the variation of forces and torques in the robot joints. They could be used, in our future work, for studying the joints behavior, by using the finite element analysis method.

References

[1] Ratiu M and Rus A 2017 Modeling of the trajectory-generating equipments *IEEE publication 14th International Conference on Engineering of Modern Electric Systems (EMES)*

[2] Tarabanov E 2006 *The virtual prototyping of robots dynamics*

[3] Ivaldi S, Padois V and Nori F 2014 *Tools for dynamics simulation of robots: a survey based on user feedback* Available on www.codyco.eu EU Project CODYCO

[4] Ratiu M, Rus A and Balas M L 2018 Modeling in ADAMS of a 6R industrial robot, *Annual Session of Scientific Papers IMT ORADEA 2018 (MATEC Web of Conferences)* **184**, 02006

[5] Ratiu M, Rus A and Balas M L 2019 *Kinematic modeling of a 6R industrial robot IOP Conf. Series: Materials Science and Engineering* **568** (2019) 012021

[6] *Getting started using ADAMS/View* 2014 retrieved from mscsoftware.com on September 2015

[7] *Adams Tutorial Kit for Mechanical Engineering Courses (Third Edition)* 2015

[8] *MSC Software: Designing Better Industrial Robots with Adams Multibody Simulation Software* Whitepaper 2016 retrieved from https://files.mscsoftware.com on July 2017

[9] Craig J 2005 *Introduction to robotics. Mechanics and control* (Pearson Prentice Hall: USA)

[10] Spong M W, Hutchinson S and Vidyasagar M 2004 *Robot dynamics and control* (Wiley)

[11] Featherstone R 2014 *Rigid body dynamics algorithms* (Springer)

[12] Featherstone R and Orin D E 2016 Dynamics, *Springer Handbook of Robotics* pp 37-66

[13] Yan Q, Zhang J, Li B and Zhou L 2019 Kinematic analysis and dynamic optimization simulation of a novel unpowered exoskeleton with parallel topology *Journal of Robotics* **2019** (Hindawi)

[14] Kumar v 2019 Kinematics/dynamics analysis with ADAMS/MATLAB co-simulation of a SolidWorks designed spatial robot arm *EasyChair Preprint* **1619**

[15] Parthasarathy T, Srinivasaragavan V and Santhanakrishnan S 2016 ADAMS-MATLAB co-simulation of a serial manipulator *ICMME 2016 (MATEC Web of Conferences)* **95**, 08002

[16] Baglioni S, Cianetti F, Braccesi C and De Micheli D M 2016 Multibody modelling of N DOF robot arm assigned to milling manufacturing *J. of Mech. Sc. and Technol.* **30** (1) pp 405–420

[17] Yang L and Zhang X 2015 Dynamics Modeling and Simulation of Robot Manipulator *Intelligent Robotics and Applications ICIRA* **2015** part III pp 525–535 (Springer)

[18] Li G, Shi B and Liu R 2019 Dynamic modeling and analysis of a novel 6-DOF robotic crusher based on movement characteristics *Mathematical Problems in Engineering* **2019** (Hindawi)

[19] Enescu M 2013 Mechatronic model for the dynamic analysis of a robotic system *Bulletin of the Transilvania University of Braşov Series I: Engineering Sciences* **6** (55) /2

[20] Alexandru C 2006 Modeling in mechatronic concept and virtual testing of orientation mechanisms used in solar panels *Mechanism and Manipulators Magazine* **2/2** pp 49-54

[21] Alexandru C 2019 Multi-body system simulation of the sun trackers used for PV panels *IOP Conf. Series: Materials Science and Engineering* **568** (2019) 012001

[22] Enescu M and Alexandru C 2011 Modeling and simulation of a 6 DOF robot *Proceedings of 2011 International Conference on Optimization of the Robots and Manipulators* (Sinaia, Romania)