TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 55, Issue II, 2012

MATLAB/SIMULINK SIMULATION AND VALIDATION OF THE KINEMATICS MODEL OF A HYBRID ROBOT FOR MINIMALLY INVASIVE SURGERY

Andras Csaba SZILAGHYI, Doina PISLA

Abstract: *In this paper a simulation model of a hybrid robot, developed for applications in minimally invasive surgery is presented. The movements of the end-effector are simulated using the Simulink model. A simulation based on the developed kinematics models is performed, using as input data the numerical values of the displacements, velocities and accelerations of the actuators. The numerical results obtained after simulation show that the model is correct and reliable, validating at the same time the kinematics models.*
Key words: *Matlab, Simulink, Simulation, Model, Hybrid robot, Minimally Invasive Surgery (MIS).*

1. INTRODUCTION

Simulation is the imitation of the operation of a real-world process or system over time [1]. The act of simulations first requires for a model to be developed. This model represents the key characteristics or behaviors of the selected physical system or process. The model represents the system itself and the simulation process represents the operation of the system over time. The simulation process is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training and education. This technique can be used to show the eventual real effects of alternative conditions and courses of actions, when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist [2].

Key issues in simulation include acquisition of valid source information about the relevant selection of key characteristics and behaviors, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes.

Simulation has been recognized as an important research tool since the beginning of the 20th century. However, the “good times” for simulation started with the development of computers and now the simulation is a powerful visualization, planning, and strategic tool in different areas of research and development [3].

The simulation has also a very important role in robotics. Different tools are used for the analysis of kinematics and dynamics of robotic manipulators, for off-line programming, to design different control algorithms, to design mechanical structure of robots, to design robotic cells and production lines, etc.

A robotics simulator is used to create embedded applications for a specific (or not) robot without being dependent on the “real” robot. In some cases, these applications can be transferred to the real robot without modifications. In the robotics field the simulation, allow to reproduce situations that cannot be “created” in the real world because of cost, time, or the “uniqueness” of a resource.

Matlab/Simulink [4], [5], [6], [7] has become the most widely used software package for modeling and simulating mechanical systems. The digital-control model adopted for the simulation of a hybrid robot, designed for applications in minimally invasive surgery is described in this paper. A simulation (a case study), with the virtual robot is performed by using the digital control model. The results show that the simulation model is reliable.

2. MATLAB/SIMULINK ENVIRONMENT

Considering the advances of the control theory and computer techniques, the computer aided control system design (CACSD) has been developed. MATLAB is one of the representatives of the high-performance languages for the CACSD. Simulink, developed by MathWorks, is a commercial software package for modeling, simulating and analyzing multi-domain dynamic systems. It supports linear and non-linear systems, modeled in continuous time, sampled time, or a hybrid combination of the two. Simulation is an interactive process, so one can change parameters ‘‘on the fly’’ and immediately see what happens [8]. One has instant access to all of the analysis tools in MATLAB, so one can analyze and visualize the results. For modeling, Simulink provides a graphic user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi-domain simulation and Model-Based Design [9], [10].

3. DESCRIPTION OF THE ROBOTIC SYSTEM

The main requirements of surgeons imposed on a surgical robot used for minimally invasive surgery are the following: the robot control has to be accurate, it has to be stable and rigid in the operating room, it should occupy a minimum space in the patient proximity; in addition to these technical characteristics, the safety features must prevent the patient or surgeon from harm, in case of a robot malfunction [11].

The particularities and motions of two different 3-DOF parallel robots for MIS have been presented in [12], [13], [14] (PARAMIS) and [15] (PARASURG), which can be used only as laparoscope holders.

The PARAMIS robotic structure with 3 DOF was created to respond to the surgeon’s demand, having a simple and compact solution for the positioning of the endoscope in minimally invasive surgeries. Considering the positive results obtained from experimental tests and the PARAMIS robot form, which minimizes the space occupied in the proximity of the patient, following the idea of modularity, instead of developing something completely new, the development of a single module was chosen. The new robot structure increases the applicability of PARAMIS which can be used only as laparoscope holder, proposing a new solution capable of positioning the active instruments used for cutting, suturing, grasping etc.

In order to develop the new system, starting from the existing one, which could manipulate an active instrument, an improvement of the robot was proposed by attaching a module with 2 DOF. The kinematic scheme of the new module is shown in figure 1, illustrating the last two active joints q_4 and q_5, where q_4 achieves a rotational motion around the axis Z’, which is parallel to the Z axis of the fixed coordinate system OXYZ, and q_5 achieves a rotational motion around the axis Y*, which is an axis situated in a parallel plane with the fixed plane XOY. Angles ψ and θ are also presented in figure 1.

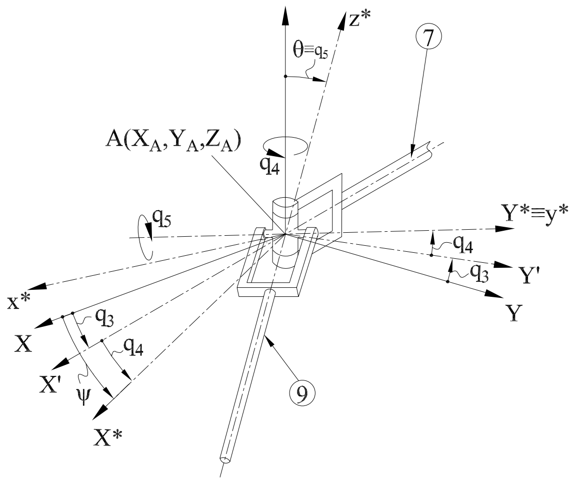

Fig. 1. The kinematic scheme of the new module.

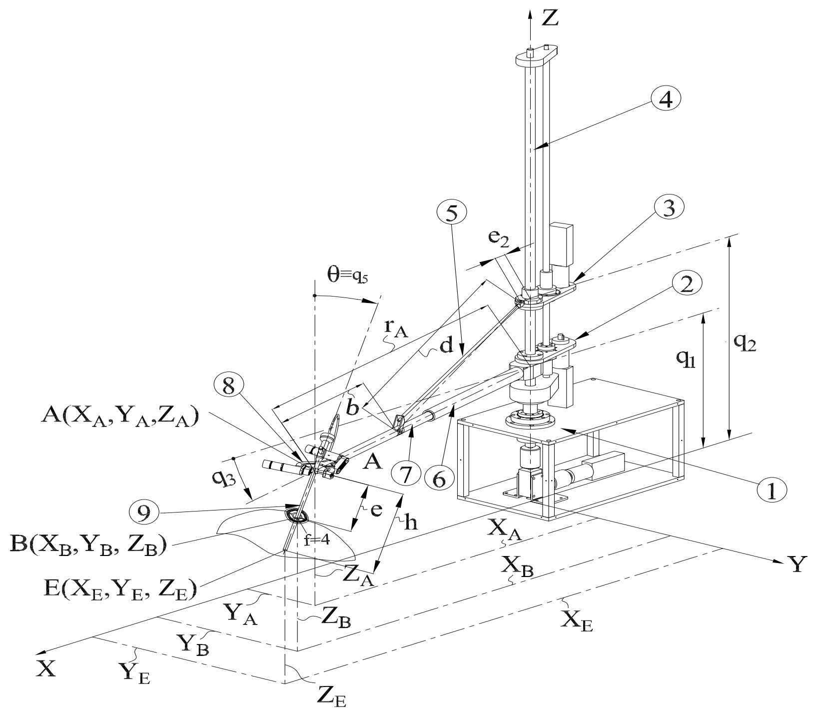

Fig. 2. Schematic representation of the hybrid robot integrating the new module.

The first two active joints q_1 and q_2 are translational joints positioned on a vertical bar, and the third joint, q_3 achieves a rotational motion from the base of the robot (Fig. 2.).

The new hybrid robot with five motors based on an already existing robot and the attachable serial orientation module, allows manipulation of the instruments. The motivation for choosing a parallel-serial configuration is given by its architectural advantages. This hybrid parallel robot (Fig. 2.) has the following advantages: having an orientation module at the end of arm 7, the positioning and orientation of the robot being achieved by means of five motors, thus the „natural" fixed joint, provided from the fixed entrance point in the surgical area, is replaced by the virtual fixed point, which is provided by the two additional active joints (q_4 and q_5). In this way, the robot can guide an active surgical instrument that interacts with internal organs.

The robotic arm (Fig. 2.) composed from the positioning parallel module with 3 motors (PARAMIS), and the orientation serial module with 2 motors, uses its five active joints (q_1, q_2, q_3, q_4, q_5) and several passive joints (two rotational joints and one prismatic joint) to fulfill its task. From the first three active joints, two of them are prismatic and one is rotational, the other two active joints on the tip of the arm r_A being rotational joints. The passive joints of the hybrid structure are: two rotational joints (between elements (3) and (5), respectively (5) and (7)), one prismatic joint (between elements (6) and (7)). The geometric parameters of the robot are represented by: d (length of element 5), b (length of element 7), h (length of surgical instrument), e_2 (eccentricity of element 3) and the coordinates of the entrance point in the abdominal area ($B(X_B, Y_B, Z_B)$). The surgical instrument can be positioned in any point of the surgical field using the 5 motors of the robot to offer for surgeons the best possible details of the surgical field and to have the full control over the instrument motions during surgery.

An important advantage of this hybrid robot is a better guidance of the camera and the possibility to position an active instrument.

4. MODELING OF THE ROBOTIC SYSTEM IN SIMULINK

For control studies of the hybrid robotic system, based on the developed kinematics model, a simplified Simulink model is built, without introducing frictions in joints, but respecting the constructive dimensions and the geometrical parameters of the mechanical structure.

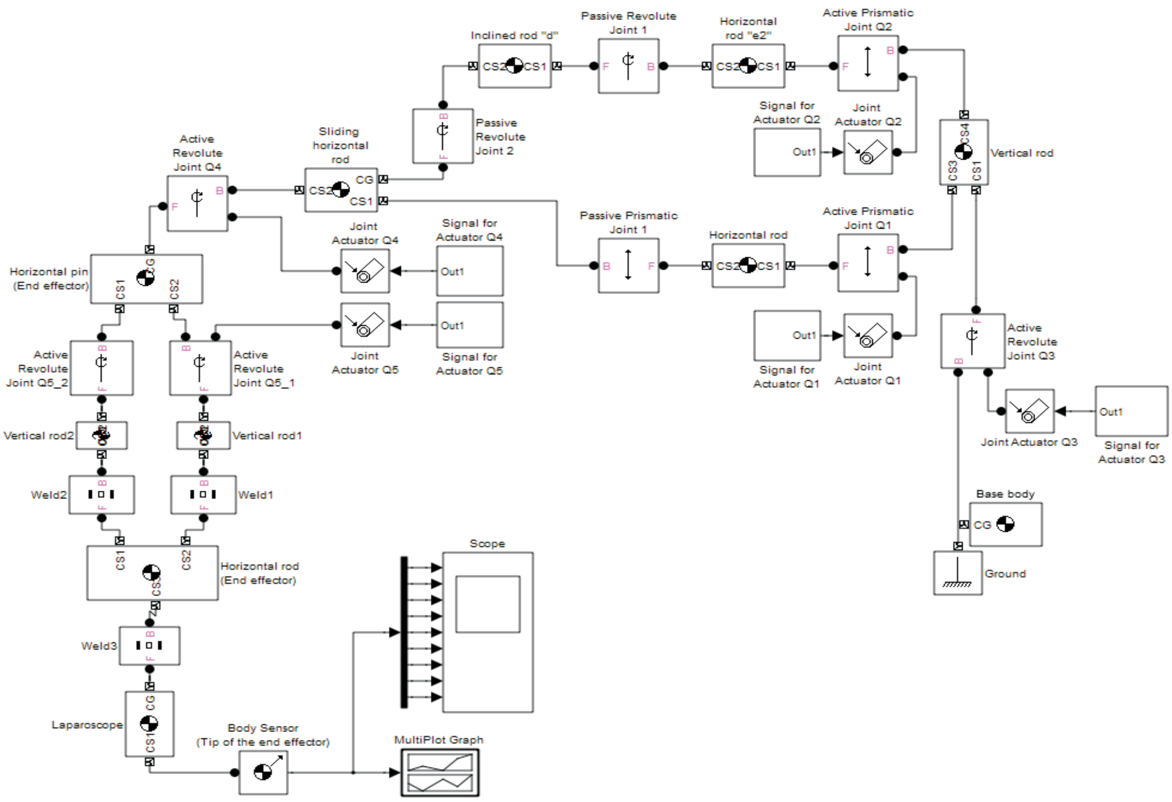

Fig. 3. The robotic structure layout based on Simulink block diagrams.

The Simulink model of the robot is made up of the controlled object (the mechanical structure) and the controllers (the five actuators). As controlled object, Fig. 3 shows the robot mechanical structure layout, assembled using the Simulink block diagrams.

As input data for simulation, the calculated displacements, velocities and accelerations, based on the inverse kinematics model, were used. These models were implemented in MATLAB as functions, after running these functions, the numerical values of the displacements, velocities and accelerations are obtained and stored in the computer memory or are saved in a separate file.

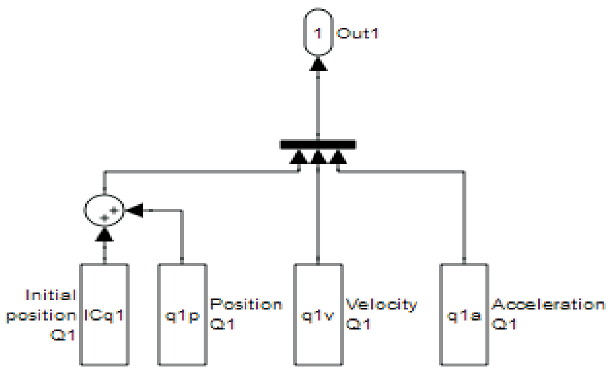

Fig. 4. Subsystem for input data.

Using a subsystem (Fig. 4) for each actuator, the numerical values of the linear/angular position, velocity, and acceleration, are imported in Simulink and bundled into one motion signal.

Using a sensor block diagram attached to the tip of the end-effector, the displacements, velocities and accelerations can be measured in that point. The obtained data can be represented in graphical form using the "Multi Plot" or the "Scope" block diagram (Fig. 3).

5. SIMULATION RESULTS

In case of the hybrid robot used in minimally invasive surgery, in order to perform the imposed movements given by the surgeon, the structure is supposed that its end-effector longitudinal axis always passes through a fixed point (B) defined in space, which is the intersection point between the abdomen and the end-effector. For the simulation experiment it was chosen the command MOVE UP [16], which means a motion of the end-effector from the initial position and orientation with 5º (five degrees) to the upper direction, from the surgeon’s view. In kinematics terms, the motion represents a rotation around an axis with the origin in B, perpendicular on the longitudinal axis of the laparoscope, this axis being contained in a plane parallel with the horizontal one (XOY). Using a set of initial coordinates (X_{Ei}=1080 mm, Y_{Ei}=40 mm, Z_{Ei}=550 mm) for the tip of the end-effector and following the MOVE UP command, the coordinates of the final position were determined (X_{Ef}=1087.3 mm, Y_{Ef}=44.2 mm, Z_{Ef}=557.4 mm), respecting the imposed geometrical restriction represented by the fixed point B with coordinates (X_B=1010 mm, Y_B=0 mm, Z_B=650 mm).

Using the Simulink graphical user interface, the model of the robot built up from block diagrams, can be represented as a 3D model (Fig. 5), also allowing the visualization of the simulated movements in real time.

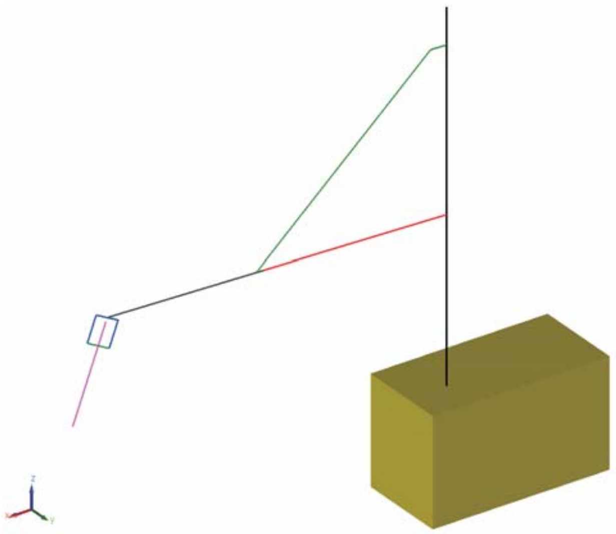

Fig. 5. Simulink 3D model.

To verify and validate the numerical results obtained, following the implementation of the inverse and direct kinematics models in MATLAB functions, the above presented Simulink model was used. During the simulation, with a body sensor (Fig. 3), the variations of parameters of the tip of the end-effector were acquired and using the "Multi Plot" function, were represented in a graphical form in figure 6, illustrating the time history diagrams of the displacements, velocities and accelerations.

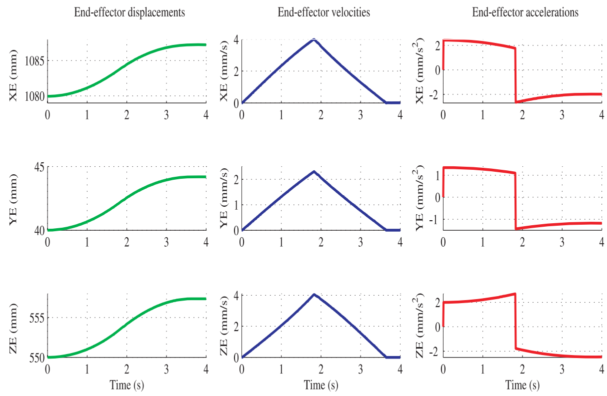

Fig. 6. Simulink simulation results for the end-effector.

Analyzing the time history diagrams, obtained by following the numerical simulation of the direct kinematics model, and by following the Simulink simulation (Fig. 6), the results prove to be identical, thus the obtained results are validated and the accuracy of the developed kinematics models is confirmed.

6. CONCLUSION

In this paper, a Matlab/Simulink model of a hybrid robot for minimally invasive surgery and its control simulation, based on the direct kinematics, are presented. The simulation experiment of this model is performed using as inputs digital motion signals for the actuators. The comparison of the calculated data with the measured simulation results shows that the developed kinematics models for the control of the robotic system is reliable and can be used in the control system of the real robot.

Acknowledgements

This paper was supported by the projects "Doctoral studies in engineering sciences for developing the knowledge based society-SIDOC” contract no. POSDRU/88/1.5/S/ 60078, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013 and Scopes International Grant IZ74Z0-137361 entitled Creative Alliance in Research and Education focused on Medical and Service Robotics (CARE-Robotics).

7. REFERENCES

[1] Banks J., Carson J., Nelson B., Nicol D., *Discrete-Event System Simulation*, Prentice Hall, p. 3, ISBN 0-13-088702-1, 2001.

[2] Sokolowski J. A., Banks C.M., *Principles of Modeling and Simulation*, Hoboken, John Wiley, p. 6, ISBN 978-0-470-28943-3, 2009.

[3] Žlajpah L., *Simulation in robotics,* Mathematics and Computers in Simulation, Volume 79, Issue 4, pp. 879-897, 2008.

[4] *Matlab – the language of technical computing,* Using MATLAB, 6th. Natick, The Mathworks Inc., 2001.

[5] *Simulink – model-based and system-based design,* Using Simulink, 4th. Natick, The Mathworks Inc., 2001.

[6] Duran F., et al., *Simulink stateflow for algorithm learning*, Procedia - Social and Behavioral Sciences, Volume 1, Issue 1, pp. 554-558, 2009.

[7] *MATLAB/Simulink tutorials* – http://www. mathworks.com/academia/student_center/tutorials/simulink-launchpad.html

[8] Yu Y., Chen L., Sun F., Wu C., *Matlab/Simulink-based simulation for digital-control system of marine three-shaft gas-turbine,* Applied Energy, Volume 80, Issue 1, pp. 1–10, 2005.

[9] *The Successful development process with MATLAB Simulink in the framework of ESA's ATV project*, http://www.vega-group.com/assets/documents/10000421matlabsimulink.pdf.

[10] *Model Based Design Accelerates the Development of Mechanical Locomotive Controls*, SAE 2010 Commercial Vehicle Eng. Congress, Chicago, IL, USA, 2010.

[11] Taylor R. H., Kazanzides P., *Medical Robotics and Computer-Integrated Interventional Medicine*, Advances in Computers, Vol. 73, pp. 219-260, 2008.

[12] Vaida C., *Contributions to the development and kinematic - dynamic modeling of parallel robots for minimally invasive surgery*, (published in Romanian), PhD. Thesis, http://www.utcluj.ro/download/ Rezumat_Calin_VAIDA.pdf

[13] Gherman B., Vaida C., Pisla D., Plitea N., Gyurka B., Lese D., Glogoveanu M., *Singularities and workspace analysis for a parallel robot for minimally invasive surgery*, IEEE International Conference on Automation Quality and Testing Robotics (AQTR), Cluj-Napoca, Romania, pp. 1-6, ISBN: 978-1-4244-6724-2, DOI: 10.1109/AQTR.2010.5520866, 2010.

[14] Plitea N. et. al., *Innovative development of Parallel Robots*, Meditech 2007, Cluj-Napoca, Romania, published in Acta Electrotehnica ISSN 1841-3323, pp. 201-206, 2007.

[15] Pisla D., Plitea N., Gherman B., Pisla A., Vaida C., *Kinematical Analysis and Design of a New Surgical Parallel Robot*, Computational Kinematics, Springer, pp. 273-282, 2009.

[16] Vaida C., et. al., *Development of a Voice Controlled Surgical Robot*, Mechanisms and Machine Science, Vol. 5, Part 10, 567-574, DOI: 10.1007/978-90-481-9689-0-65, 2010.

SIMULAREA ŞI VALIDAREA PRIN MATLAB/SIMULINK A MODELELOR CINEMATICE AL UNUI ROBOT HIBRID PENTRU CHIRURGIA MINIM INVAZIVĂ

În lucrare este prezentat un model de simulare al unui robot hibrid dezvoltat pentru aplicații în chirurgia minim invazivă. Utilizând modelul Simulink, sunt simulate mişcările efectorului final. Simularea este bazată pe modelele cinematice dezvoltate, utilizând ca şi date de intrare valorile numerice ale deplasărilor, vitezelor şi accelerațiilor motoarelor. Rezultatele simulării arată că modelul de simulare este corect şi de încredere, validând în acelşi timp modelele cinematice.

András Csaba SZILÁGHYI, PhD. student Eng., Technical University of Cluj-Napoca, Department of Mechanical Systems Engineering, e-mail: sz_a_cs@yahoo.com, ☎+40-264-401684, 103-105, Muncii Blvd, Cluj-Napoca, RO 400641, ROMANIA.

Doina PÎSLĂ, Corresponding Author, Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Mechanical Systems Engineering, e-mail: doina.pisla@mep.utcluj.ro, ☎+40-264-401684, 103-105, Muncii Blvd, Cluj-Napoca, RO 400641, ROMANIA