Virtual Instrumentation in the Robot's Kinematics Velocities Analyze

Adrian D. Olaru, Serban A. Olaru, Niculae C. Mihai, and Natalia M. Smidova

***Abstract*—For the robot's dynamic behaviour analyse will be necessary to know the positions, velocities, accelerations of all robot's joints. For that firstly will be necessary to know the positions and secondary the angular and linear velocities in all robot's joints. The LabVIEW software from National Instruments, USA, assures one easily way to obtain the information, in matrix form, about the joint's positions and velocities and compare them with the data acquisition, information that could be used in the future, in the assisted dynamic behaviour. In the paper was shown some different cases of the relative joint's velocities. The applied method solves one small part of the complex problems of the robot's kinematics.**

***Index Terms*—Virtual instrumentation, assisted research, 6x6 transfer matrix, dual angular and linear velocity vector, antisymmetric position vector, dual velocity 6x6 matrix equation.**

I. Introduction

The velocities analyze in Robotics is one of the most important problem of the robot's kinematics. Without the assisted research with the LabVIEW software will not be possible to study the kinematic and dynamic behavior.

In addition to finding the end-effecter position for given joint parameters, in forward and inverse kinematics, the robot's kinematics also includes the analysis of manipulators in motion. Not only the final position of the links and joints to attain the desired position of the end-effecter, but also the velocity, and its variation, of the links and joints of the robots while attaining the final position is important for analysis [1].

Especially in the last two decades, there are various toolbox studies on forward and inverse kinematic analyses of serial robots [2]-[12]. Some of these are open source and free toolboxes for educational use. Some of them are commercial and non-open source, which can be used to analyse industrial robots that used. Except these, they do not work when the analyse of specially designed robots with a high degree of freedom, such as those used for space for research purposes, or any serial robot, designed by students for educational purposes.

Manuscript received April 30, 2019; revised July 2, 2019. This work was supported in part by the RUSOS European project and was realized together with University Politehnica of Bucharest, the mechatronics companies ACTTM from Romania, Techno Accord from Quebec, Canada and Kosice University of Technology, Slovakia.

A. D. Olaru is with the University Politehnica of Bucharest, Romania, 60042, Romania (e-mail: aolaru_51@ymail.com).

S. A. Olaru was with ACTTM Company, Bucharest, Romania (e-mail: serban1978@yahoo.com).

N. C. Mihai is with the TechnoAccord SA, Quebec, Canada (e-mail: mniculae@gmail.ca).

N. M. Smidova is with Kosice University of Technology, Slovakia.

The assisted research was made by using the proper virtual LabVIEW instrumentation and the acquisition board from National Instruments, USA. The stand that used for the research is shown in Fig. 1.

MATLAB [13] is a powerful environment for linear algebra and graphical presentation that is available on a very wide range of computer platforms. The core functionality can be extended by application specific toolboxes. The Robotics Toolbox provides many functions that are required in robotics and addresses areas such as kinematics, dynamics, and trajectory generation. The Toolbox is useful for simulation as well as analyzing results from experiments with real robots, and can be a powerful tool for education.

The paper [14] has demonstrated the principle features of the Robotics Toolbox for MATLAB. "The Toolbox provides many of the essential tools necessary for robotic modelling and simulation, as well as analyzing experimental results or teaching. A key feature is the use of a single matrix to completely describe the kinematics and dynamics of any serial-link manipulator" [14].

In the book [15] was proposed one method by using the Jacobian matrix after was applying the first derivate function of the position. Mathematically, the forward kinematic equations define a function between the external coordinates and the internal coordinates, the relation between the coordinates of the end-effecter and the internal coordinates of the joints. The velocity relationships are then determined by the Jacobian of this function. This Jacobian matrix is one of the most important quantities in the analysis and control of robot motion, but impose to use some complex mathematic form of the equations.

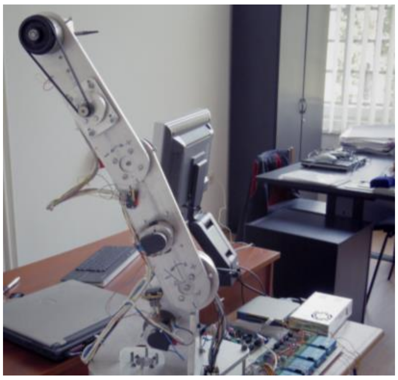

Fig. 1. The experimental stand used in the assisted research.

In [16]-[20] papers are presented some relations of the end-effecter and joints angular and linear velocities determined also by using the Jacobian matrix form, not some transformation matrix or matrix form like will be used by the proposed algorithm.

In the book [21], the authors shown the matrix method of the velocity in forward and inverse kinematics, but also with

DOI: 10.7763/IJMO.2019.V9.720

determination the Jacobian matrix. It is shown the singularity conditions and applicability.

A. The Velocity Mathematical Matrix Model

The matrix form of the positions, velocities, accelerations, forces and moments equations assure the easily way for the assisted research of the kinematics and dynamics behavior of robots. The matrix equations for the positions and velocities are:

$$(r_i^0) = (r_{i-1}^0) + [D_{i-1}^0](r_i^{i-1}) \tag{1}$$

$$\begin{pmatrix}(\omega_{i,0}^i)\\(v_{i,0}^i)\end{pmatrix} = [T_{i-1}^i]\begin{pmatrix}(\omega_{i-1,0}^{i-1})\\(v_{i-1,0}^{i-1})\end{pmatrix} + \begin{pmatrix}(\omega_{i,i-1}^i)\\(v_{i-1,i}^i)\end{pmatrix} \tag{2}$$

$$\begin{pmatrix}(\omega_{i,0}^0)\\(v_{i,0}^0)\end{pmatrix} = \begin{bmatrix}[D_i^0] & [0]\\ [0] & [D_i^0]\end{bmatrix}\begin{pmatrix}(\omega_{i,0}^i)\\(v_{i,0}^i)\end{pmatrix} \tag{3}$$

$$[T_{i-1}^i] = \begin{bmatrix}[D_{i-1}^i] & 0\\ -[D_{i-1}^i][\hat{r}_i^{i-1}] & [D_{i-1}^i]\end{bmatrix} \tag{4}$$

(r^0_i) is the column matrix vector for absolute position *i* joint versus the zero point; *(r^0_{i-1})*- column matrix vector for absolute position *i*-1 joint; $[D^0_{i-1}]$-quadratic matrix for transfer vector from *i*-1 to base system;

where: $\begin{pmatrix}(\omega_{i,0}^i)\\(v_{i,0}^i)\end{pmatrix}$ is the dual matrix vector for absolute velocity *i* joint reduced to the *i* Cartesian System; $\begin{pmatrix}(\omega_{i-1,0}^{i-1})\\(v_{i-1,0}^{i-1})\end{pmatrix}$ - dual matrix vector for absolute velocity *i*-1 joint reduced to the *i*-1 Cartesian system; $[T^i_{i-1}]$- quadratic matrix 6×6 for transferdual velocity vector from *i*-1 to *i* Cartesian system; $\begin{pmatrix}(\omega_{i,i-1}^i)\\(v_{i,i-1}^i)\end{pmatrix}$- dual matrix vector for relative velocity between *i* joint and *i*-1, reduced to *i* Cartesian system.

Relation (1) is the matrix form of the position robot's joints equation. The relative position vector is used to define anti symmetric position vector to construct the matrix product between angular and linear velocities. In this matrix form used the transfer matrix *T*, eq.(4) between the different robot's joints cartesian systems. With this matrix operator easily was defined the absolute and relative dual column matrix velocities vector, eq.(2) and (3). With matrix eq.(3) will be determined the absolute dual velocity vector reduced to the base Cartesian system, known the dual absolute velocity vector reduced to the current joint, eq.(2). In the proper assisted research papers with LabVIEW instrumentation [22]-[36] was shown some results that can be used by the researchers in the robot design activities in the kinematics and dynamics of robots.

In all assisted research cases with the goals: the design, modeling and simulation, was offered some on-line results what can be used to choose some optimal values of the constructive and functional parameters to obtain one required kinematic and dynamic behavior: one short acceleration time in concordance with the accepted vibration field, without vibration components in the resonance field, minimal stationary errors of the space trajectory of the end-effecter, one bigger Bode frequency to assure one minimum acceleration time, one higher cutting Bode frequency, one higher proper and natural frequencies.

B. The LabVIEW Virtual Instruments

The Figs.2-5 shown some virtual instruments (VI) used in the assisted research of the robot's velocities.

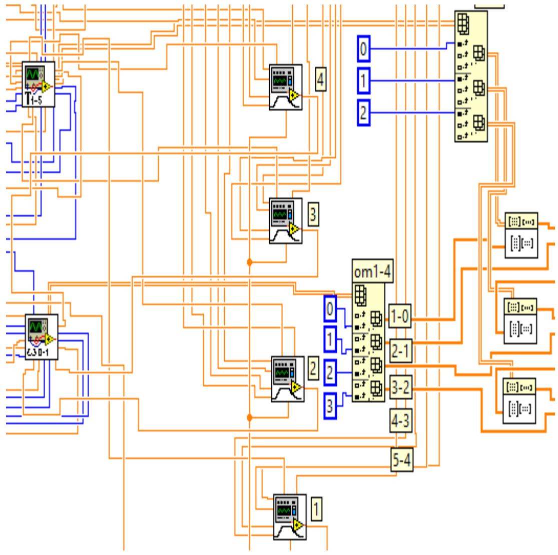

Fig. 2. Part of the block schema of the *VI*-s to determine the absolute velocities dual vector versus current cartesian system

The base program, Fig. 2, contents some sub *VI*-s that could be used in many other LabVIEW programs. The base program used the sub*VI*-s to determine all dual absolute and relative vector of velocity, to generate the matrix form 6x6 for transfer the dual vectors between one Cartesian system to one other, the sub*VI*-s to transform the data from the cluster to the matrix and the sub*VI*-s to generate the trapezoidal characteristics of the relative velocity in all robot's joints.

All these sub*VI*-s could be used in many other LabVIEW applications.

C. The Front Panel of the Proper Virtual LabVIEW Instrumentation with Input Data

The front panels contents the input data and the results of the simulation. Some part of the front panels from the sub*VI*-s are shown in Figs. 3-5. In Fig.3 is shown the front panel to generate the dual vector of the angular and linear velocity. The input data contents the type of the robot's module (Translation or Rotation), the velocity value in the robot's joint and the axes of the rotation or translation. In fig.4, was construct the table of all relatives velocities of the robot by declare for each robot's degree of freedom (DOF), the input data similar like in Fig. 3.

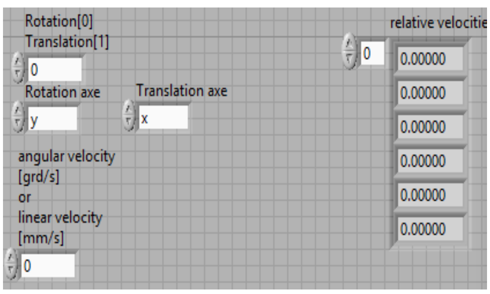

Fig. 3. The front panel of the *VI*-s to determine the dual vector of angular and linear velocity.

The front panel of the Figs. 4-5 shown the table with three dimensions with the transfer matrices *T*, between all Cartesian systems. The transfer matrices *D* are used for the transfer of the vector from one system to other with 3x3 dimensions. The joint's position vectors in 3D robot's working space and the trapezoidal characteristics of the velocities are used to solve the Forward Kinematics (FK) to determine the absolute positions, velocities and accelerations in the space of all robot's joints.

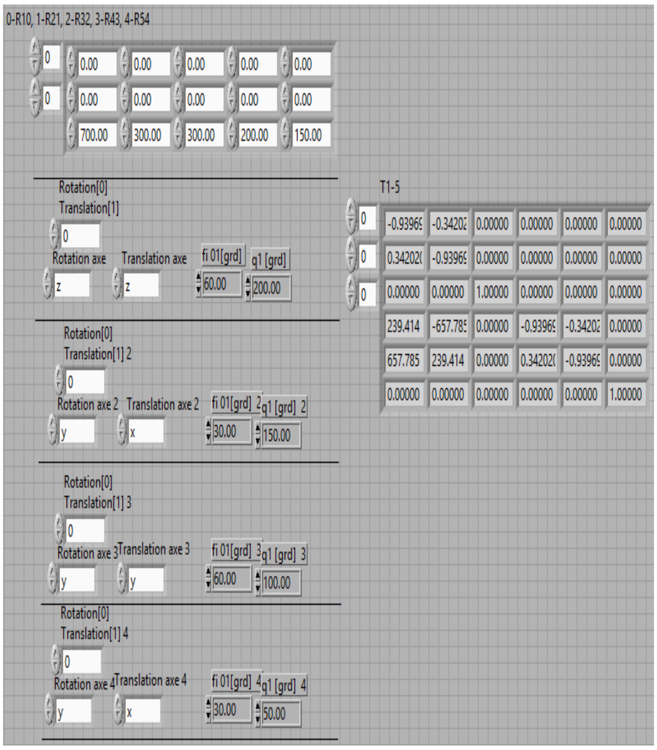

Fig. 4. Front panel to construct the transfer matrices *T* between cartesian systems.

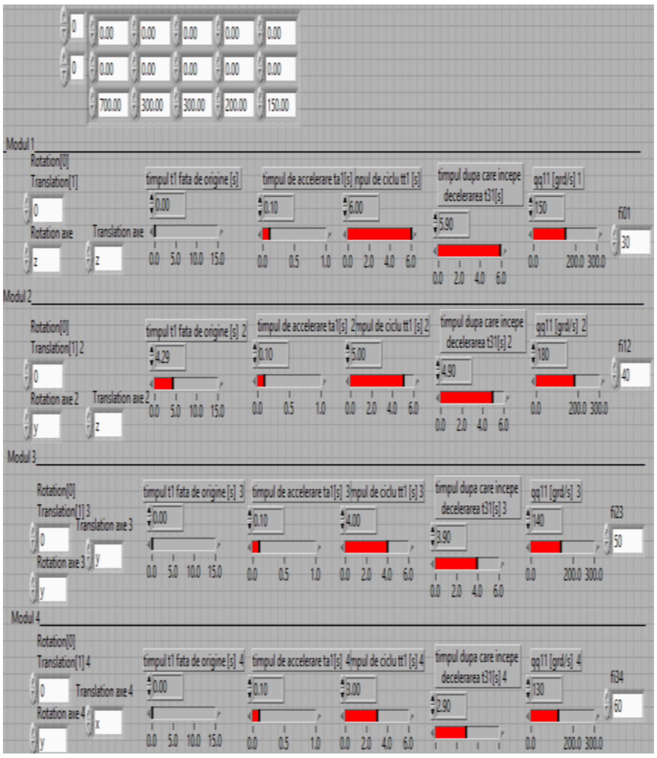

Fig. 5. Front panel of the principal program with the input data for the trapezoidal velocities characteristics and the type of each robot's modules.

D. The Results of the Assisted Research of the Velocity for Some Different Types of Movements

The theoretical assisted research with the proper LabVIEW *VI-s* was done by using different velocities characteristics like: with simultaneously movements of all joints, with successive movements or simultaneously and successive after the acceleration time, or combine two movements to be simultaneously and other successive. Some of these results are shown in Figs. 6-10.

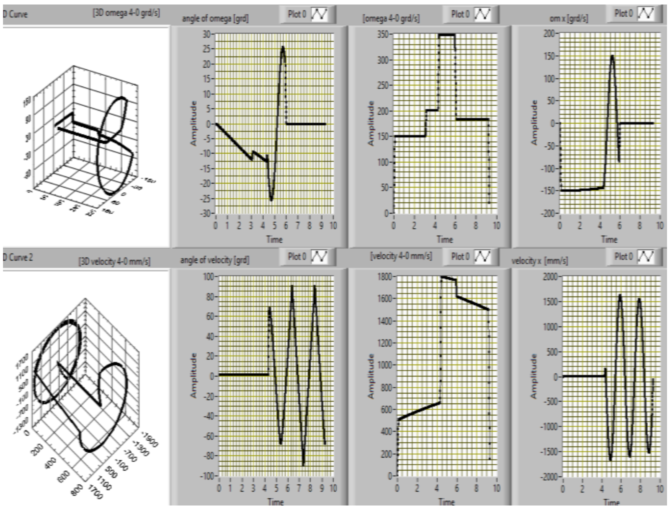

Fig. 6. The results of the 3D angular and linear absolute velocity characteristics with the successive movements: module 2 after 4,29s and module 4 after 3.05s.

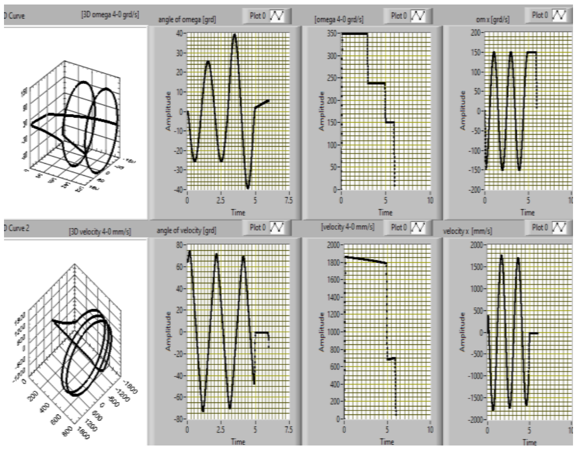

Fig. 7. The results of the 3D angular and linear absolute velocities characteristics with simultaneously movements with different cycle times.

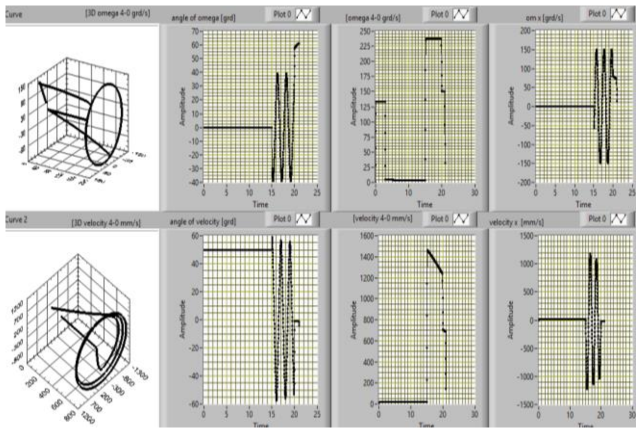

Fig. 8. The results of the 3D angular and linear absolute velocities characteristics with simultaneously movements of 1-2 modules after 15s from the origin and with simultaneously movements from the origin time of modules 3-4

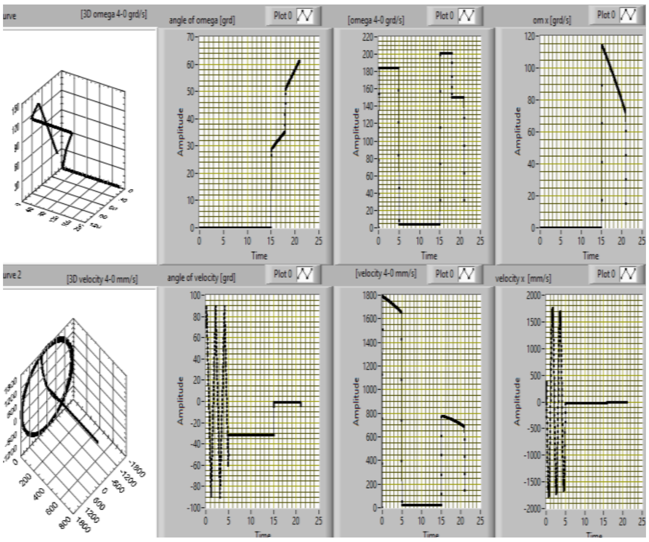

Fig.9. The results of the 3D angular and linear absolute velocities characteristics with simultaneously movements from the origin time of 1-3 modules and with simultaneously movements after 15s from the origin time of the modules 2-4.

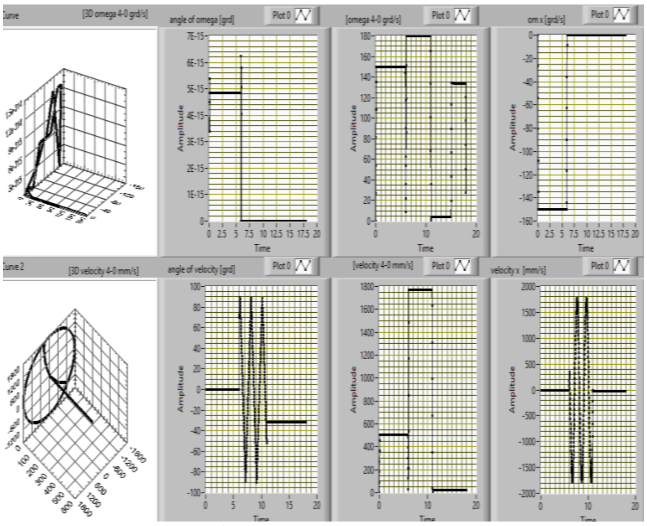

Fig. 10. The results of the 3D angular and linear absolute velocities characteristics with successive movements of the 1,2,3,4 modules from the origin time.

In the simulation activities, to be assured good results, we used the characteristics of relative joint's velocities in some different cases: simultaneously, successive, successive-simultaneously after acceleration time, successive-simultaneously after the constant velocity period, successive after the deceleration time, simultaneously with the same or different velocities values. In all studied cases must be shown the maximal variation of the linear and angular velocities that could be influence the dynamic behavior of the robot in different types of applications.

II. Optimization of the Robot's Kynematics by Using the Assisted Research Results

What must be the movements cases to be obtained some optimal results of the velocities variation? The analyze of the simulation results assure the answer at this question.

After the analyze of the simulation's results could be make the following observations: (i) angular velocities are minimum in the cases of the movements with simultaneously movements from the origin time of 1and 3 modules and with simultaneously movements after 15s from the origin time of the modules 2 and 4, Fig. 9, successive movements of the 1,2,3,4 modules from the origin time, Fig. 10, successive movements of the 1,3,2,4 modules from the origin time, successive movements of the 1,4,2,3 modules from the origin time, that determine the minimum of the centrifugal forces, the minimum of the Coriolis forces and also the inertial moments; (ii) linear velocities are minimum in the fig.9 in the same cases of the movements, that determine the minimum of the Coriolis forces, the minimum of the dynamic impulse and also the minimum of the inertial forces; (iii) the most unfavorable case is when the linear or angular velocity vector has a multiple cyclic variation after a circle of variation, between the minimum and maximum values: for the angular velocity of -250grd/s to 250grd/s and -1200mm/s to 1200mm/s for linear speed; (iv) cyclic variation of the angular velocity's angle between -25 to 25grd, -40 to 40grd, -60 to 60grd (Fig. 8) with simultaneously movements with different cycle times, simultaneously movements from the origin time of 1-2 modules and with simultaneously movements after 15s from the origin time of the modules 3-4, simultaneously movements of all modules with the same characteristics of relative velocity with 150grd/s, successive-simultaneously- successive movements after acceleration time of all modules with the same characteristics of relative velocity with 150grd/s, simultaneously movements with different velocities; (v) cyclic variation of the linear velocity's angle between -50 to 50grd, -70 to 70grd, -90 to 90grd (figs.6,7,9,10) with simultaneously movements of 1 and 2 modules after 15s from the origin and with simultaneously movements from the origin time of modules 3 and 4, simultaneously movements with different velocities, simultaneously movements with different cycle times, simultaneously movements of all modules with the same characteristics of relative velocity with 150grd/s, successive-simultaneously- successive movements after acceleration time of all modules with the same characteristics of relative velocity with 150grd/s, successive movements after different delay of time versus origin time: module 2 after 4.29s, module 3 after 3.06s, module 4 after 6.89s, simultaneously movements from the origin time of 1 and 2 modules and with simultaneously movements after 15s from the origin time of the modules 3 and 4, simultaneously movements from the origin time of 1-3 modules and with simultaneously movements after 15s from the origin time of the modules 2-4, successive movements of the 1,4,2,3 modules from the origin time, successive- simultaneously movements, successive after the constant velocity characteristic with the same velocity 150grd/s; (vi) the most favorable case, when the variation of the angle of the absolute angular velocity vector is minimum, is fig.6, with successive movements of the 1,2,3,4 modules from the origin time, successive movements of the 1,3,2,4 modules from the origin time, successive movements of the 1,4,2,3 modules from the origin time, successive- simultaneously movements, successive after the constant velocity characteristic with the same velocity 150grd/s.

After the intersection of the most favorable cases (i), (ii) and (vi) result that in the Fig. 10 are shown the best choosing of the movements cases in all joints: successive movements, or successive movements after the constant velocity value.

III. Conclusion

The assisted research proposed by this paper, the proper virtual LabVIEW instrumentation for the assisted research of the velocity open the way to the optimal assisted research in the future of the Kinematics and Dynamics for the different type of robots and for different robot's applications in singular, or multi robot application. The analyze of the velocities is one of the most important problem that must be solved in the robot's kinematics. Positions, velocities, accelerations are the most important components in the dynamic behavior equations and by known these will be possible to optimal choose the kinematic robot's parameters. The presented matrix equations, the algorithm, the virtual instrumentation are generally and they could be applying in many other robotic applications.

Acknowledgment

The authors tanks to University Politehnica of Bucharest, department of RSP, ACTTM Company, TechnoAccord Private Company and Kosice University of Technology for technical support of this research.

References

[1] Brighthubengineering. [Online]. Available: https://www.brighthubengineering.com%2frobotics%2f50038-kinematics-of-manipulators-velocity-analysis%2f&usg =aovva w 2fpsg1z4-o0vj0tu1i9lib
[2] Ö. Haluk, K. Cenk, and Z. Bingul, "Robotics toolbox for kinematic analysis and design of hybrid multibody systems," pp. 401-406, 2017.
[3] P. I. Corke, "A robotics toolbox for MATLAB," *IEEE Robot Automat*, pp. 24–32, 1996.
[4] B. Hill and D. Tesar, "Rapid analysis manipulator program (RAMP) as a design tool for serial revolute robots," in *Proc. the IEEE International Conference on Robotics and Automation*, vol. 4, pp. 2896–2901, 1996.
[5] S. Kucuk and Z. Bingul, "An off-line robot simulation toolbox," *Applications in Engineering Education*, vol. 18, pp. 41–52, 2010.
[6] J. F. Nethery and M.W. Spong, "Robotica: A mathematica package for robot analysis," *IEEE Robotics and Automation Magazine*, vol. 1, pp. 13–20, 1994.
[7] H. D. Nayar, "Robotect: serial-link manipulator design software for modeling, visualization and performance analysis," in *Porc. 7th International Conference on Control, Automation, Robotics and Vision*, Singapore, 1360–1364, 2002.
[8] C. M. Gosselin, "Simulation and computer-aided kinematic design of three-degree-of freedom spherical parallel manipulators," *Journal of Robotic Systems*, vol.12, pp. 857–869, 1995.
[9] J. P. Merlet, "Determination of the orientation workspace of parallel manipulators," *Journal of Intelligent and Robotic Systems*, vol. 13, no. 1, pp. 143–160, 1995.
[10] S. Kucuk, "Simulation and design tool for performance analysis of planar parallel manipulators," *Simulation*, vol. 88, pp. 542–556, 2012.
[11] A. Wang, "Reconfigurable kinematics of General Stewart Platform and simulation interface," University of Windsor, Windsor, Canada, 2007.
[12] Z. Q. Ding and W. H. El Maraghy, "A unified robotic kinematic simulation interface," Thesis, University of Windsor, 2005.
[13] The MathWorks, Inc., 24 Prime Park Way, Natick, MA 01760, *Matlab User's Guide*, Jan. 1990.
[14] I. Peter, Corke *A Computer Tool for Simulation and Analysis: the Robotics Toolbox for MATLAB.*
[15] M. W. Spong, S. Hutchinson, and M. Vidyasagar. Robot Dynamics and Control -Second Edition. (2004). [Online]. Available: https://www.google.com/home.deib.polimi.it
[16] R. Kinematics. Wikipedia web site. [Online]. Available: http://www.wikipedia.com
[17] R. M. Crowder, *Automation and Robotics*.
[18] J. Kay, "Introduction to homogeneous transformations and robot kinematics," Rowan University Computer Science Department.
[19] V. Hlav´aˇc, *Robot Kinematics, Faculty of Electrical Engineering Department of Cybernetics, Czech Technical University*.
[20] Society of Robot Website. [Online]. Available: http://www.societyofrobots.com
[21] K. M. Lynch and F. C. Park, *Modern Robotics Mechanics, Planning, and Control*, Cambridge University Press,2017.
[22] A. Olaru, "Assisted analyze of the extenics dependent functions in 1D, 2D, 3D and nD dimensions with LabVIEW instrumentation," in *Proc. The ICNCT2013*, Seul, 2013.
[23] A. Olaru, *Dynamic of Industrial Robots Bren Edition 2001*, vol. II, Bucharest, 2001.
[24] A. Olaru and N. Mihai, *Dynamic of Industrial Robots*, Bren Edition, Bucharest, 1999.
[25] S. Olaru, A. Oprean, and A. Olaru, "Assisted research of the new bouc-wen rheological damper," in *Proc. the OPTIROB 2008*, (Ed.) Olaru, A., pp. 143-152, 2008.
[26] A. Olaru *et al.*, "Optimizing the global dynamic compliance by using the smart damper and LabVIEW instrumentation," *Applied Mechanics and Materials*, vol. 186, pp. 26-34, 2012
[27] A. Olaru and S. Olaru, "Research of the industrial robot's viscose global dynamic damper coefficient with LabVIEW instrumentation," in *Proc. the CAX'2006,* Akademia Techniczno-Rolnicza, Bydgoszcz, 2006.
[28] A. Olaru, "Virtual LabVIEW instrumentation in the technical research of the robot's elements and the systems," Bren Publishing House, 2002, pp.68-75.
[29] A. Olaru, "Dynamic of the industrial robots," vol. 2, Bren Publishing House, 2001, pp.167-175.
[30] A. Olaru and N. Mihai, "Dynamic of the industrial robots," vol. 1, Bren Publishing House, 1999, pp. 106-120.
[31] A. Oprean and A. Olaru, "Theoretical and experimental analyze of position and velocity at articulated arm industrial robot," in *Proc. the Int. Conf. On Solid Mechanics*, Romanian Academy, 2001, pp. 230-238.
[32] A. Olaru, "Theoretical and experimental research of cinematic and dynamic behavior of industrial robots," in *Proc. Annals of DAAAM for 2001& 12th International DAAAM Symposium*, 2001, pp. 333-334.
[33] A. Olaru, S. Olaru, and N. Mihai, "Proper assisted research method solving of the robot's inverse kinematics problem," *Applied Mechanics and Materials,* vol. 555, 2014, pp. 135-147.
[34] A. Olaru, S. Olaru, and L. Ciupitu, "Assisted research of the neural network by back propagation algorithm," in *Proc. OPTIROB 2010 International Conference*, 2010, pp. 194-200.
[35] A. Olaru, S. Olaru, and N. Mihai, "Proper assisted research method solving of the robot's inverse kinematics problem," *Applied Mechanics and Materials,* vol. 555, 2014, pp. 135-147.
[36] A. Olaru, S. Olaru, and L. Ciupitu, "Assisted research of the neural network by back propagation algorithm," in *Proc. OPTIROB 2010 International Conference*, Calimanesti, Romania, May 28-th– 30-th, 2010.

Adrian Olaru finished the University Politehnica of Bucharest, the Faculty of Machine-Tools. From 1998, he is a university full professor in Machine and Manufacturing Systems Department, and he teach the following courses: industrial robots dynamics behavior, LabVIEW application in modeling and simulation of the dynamic behavior of robots, robots for neurorehabilitation and personal and social robots. He is a doctor from 1989. In the last ten years he have been leading the research projects about the computer aided research and the design for the hydraulic amplifiers of pneumatic and hydraulic screwdrivers, experimental validation for mathematical models of hydraulic elements and servo system, methodological guide for dimensioning and optimizing electrohydraulic elements, assisted research of the intelligent dampers, assisted research of the neural networks, optimizing of the robots dynamic behavior by using the Fourier proper analyzer, optimizing the dynamic compliance and global transmissibility by using the proper LabVIEW instrumentation, optimize the dynamic behavior and the space trajectory by using the proper neural network.

Serban Olaru finished the University Politehnica of Bucharest, Faculty of Machines and Manufacturing Systems, Romania. From 2008 he become the Ph.D.Eng.in the field of mechatronics. Now, he works in RomSYS private company, from Bucharest, Romania, in the department of mechatronics. He write mote than 50 research papers in the fields of intelligent damper systems, mechatronic systems, simulation and modeling with LabVIEW instrumentation.

Niculae Mihai finished the University Politehnica of Bucharest, Faculty of Machines and Manufacturing Systems, Romania. From 2006 he become Ph.D.Eng. in the field of robotics. Now, he is the manager of the private company in mechatronics systems, Technoaccord, Quebec, Canada.

Natalia Smidova was graduated from Faculty of Mathematics and Physics, Charles University in Prague in 2005, works at Department of Physics, Faculty of Electrical Engineering and Informatics, Technical University of Kosice. Oriented on investigation of material properties by spectroscopic (nuclear magnetic resonance (NMR) and Raman) methods; She is interested in polymers an polymer nanocomposites made from renewable resources.