LabVIEW Software Platform for Kinematics Analyse in Robotics

A. Olaru, T. Dobrescu, S. Olaru, and I. Mihai

***Abstract*—The paper shown one new LabVIEW software platform for the Kinematics analyse in Robotics. This platform contents some more important type of robots and the positions, velocities and accelerations assisted analyse. The program contains a case-type structure with the various types of analysed robots, which also include related Cartesian systems applied in all joints. The front panel of the program contains a two-dimensional table with the input data of all relative position vectors between all joints, clusters for defining all robot modules and clusters for defining all parameters of the trapezoidal characteristics of relative motion in all robot's joints. The clusters that define the robot modules contain information on the translation or rotation couple, the angular or linear home position and respectively the axes of movement by rotation or translation. The results are shown by 3D graphics of space trajectory, of space movement of the velocities and acceleration vectors. With this platform will be possible to quickly analyse some different variants of the movement like simultaneously, successive and complex combination between them and choose the best variant for one good dynamic behaviour without vibration, without pick of moments and forces. This software platform solves one small part of the complex problems of the robot's kinematics.**

***Index Terms*—LabVIEW software, joint's position, simultaneously movements, 3D space trajectory, 3D space velocity vector, 3D space acceleration vector.**

I. Introduction

The LabVIEW software platform cover the assisted analyze of positions, velocities and accelerations in Robotics that is one of the most important problem to be solved. Without the assisted research with the LabVIEW software will be not possible to obtain the good results of the space movements of end-effecter and movements in the space of the velocity and acceleration vectors. In [1] Ran Zhao analyze the robot in collaborative mode of work and show the space trajectory of them. Kroger, in his book [2], propose to reach a goal defined by constraints (position, velocity, acceleration, jerk,…) while respecting bounds (V_{max}, A_{max}, J_{max}, D_{max}). Dahl [3] proposed to use one-dimensional parameterized acceleration profiles along the path in joint space instead of adapted splines. This subject have been analyzed in other books and research papers like [Brady 4], [Khalil 5] and [Biagiotti 6]. [Constantinescu 7] suggested a improvement of the approach of [Shiller 8] by limitation of the jerk in joint space before to five time of maximum acceleration ($5A_{max}$) or twelfth point five of maximum velocity ($12.5V_{max}$). [Liu 9] shown a one-dimensional method by using parameterizing of linear acceleration in seven profile. Owen [10] published a work about planning the 3D trajectory. [Ahn 11] used sixth-order polynomials to represent trajectories, which is named Arbitrary States POlynomial-like Trajectory (ASPOT). Haschke in [12] proposed to generate jerk-limited trajectories from arbitrary state with zero velocity. Broquere proposed in [13] an online trajectory planner for an arbitrary numbers of independent degree of freedom (DOFs).

After were analysed the mention papers from stat of art we can do the followings remarks: i) the researchers analyse the velocity and acceleration like the first derivative, respectively second derivative of the position equation without using some matrix operators; ii) the researchers didn't show the mathematical matrix form of the positions, velocities and accelerations; iii) the control of the robot's trajectory in all joints was performed without the control of the parameters of the trapezoidal velocity; iv) current research does not include research on how simultaneous or successive movement in all joints influences the characteristics of speed, spatial trajectories and accelerations.

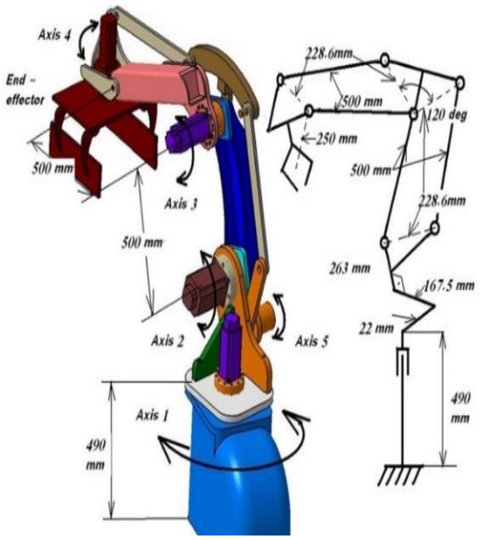

Fig. 1. The analysed robot's structure.

The paper propose to consider the analyse of robot's kinematics in one new manner: (a) by using the 6x6 matrix form of equations; (b) by transfer the kinematic equations in some LabView programs and show the characteristics in the different cases of the movements: simultaneously, successive, or combine both of them; (c) by analyse the characteristics

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that give us the possibility to establish what will be the cases where the velocities and accelerations have the maximum jerk that define the maximum of the force/moment variation and also define the non-acceptable dynamic behaviour of the movements; (d) for the assisted research was used one proper robot with parallel structure, Figs.1 and 2.

Fig. 2. The IUMIROBO for the experimental analyse by curtesy of the private company from Quebec, Canada.

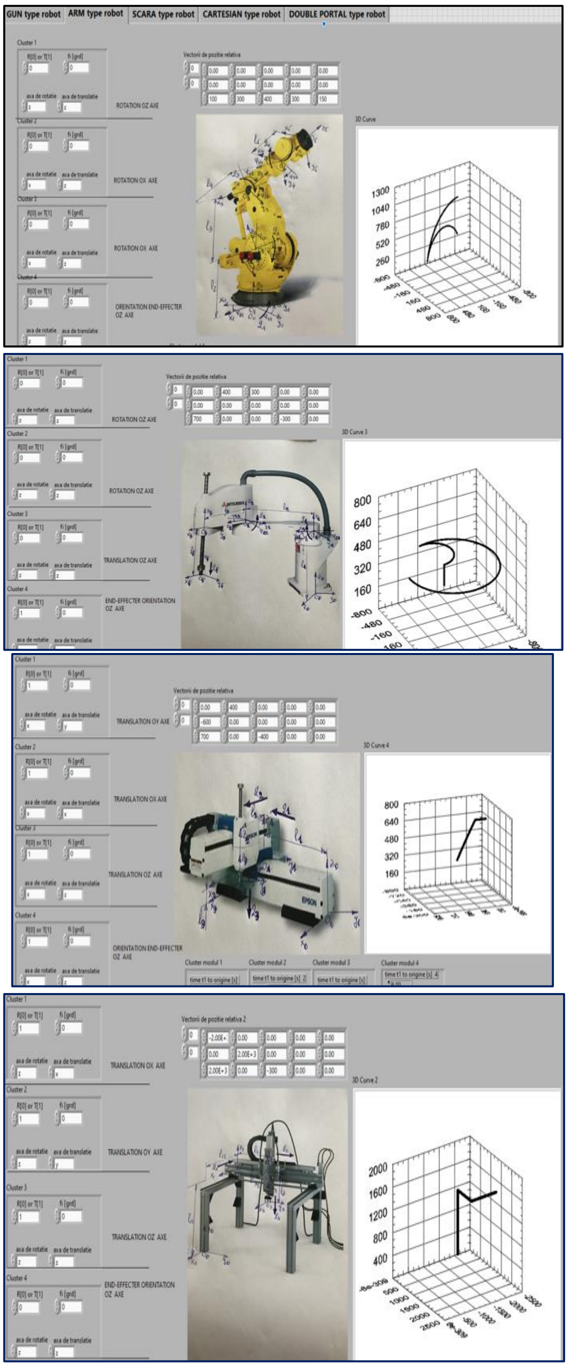


Fig. 3. Front panels with tab control of different type of robots: a). Arm type robot; b). Scara robot; c- Cartesian robot; d- Double portal robot.

II. Types of Robots in the LabVIEW Platform and Kinematics Matrix Equations

The assisted LabVIEW platform contents some of the most important type of robot that is currently used in many application. This platform could be developed in the future with many other type of robots. The proper platform was designed by using the proper matrix model used in the robots kinematic analyse. This matrix model with 3x3 and 6x6 rows was transposed in to the LabVIEW complex program. The program used the tab control to open different window for each type of robot. All these front panels are shown in Figs.3.

For the assisted research of robot's kinematics were needed the following steps: i) create the mathematical 3x3 and 6x6 matrix model; ii) construct some LabVIEW instruments that content the complex mathematical model; iii) run these virtual instrumentations to obtain the positions, velocities and accelerations characteristics versus time in some different cases of the robot's movements; iv) indicate the optimal values of the robot's types of movements after the analyse with pounder theory. Some of the proper results were obtained in the papers [14]-[18].

The dual matrix form for the velocities and accelerations equations assure the easily way for the assisted research of the kinematics and dynamics behaviour of robots.

The matrix form of the absolute vector equations for positions are:

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

The matrix form of the dual absolute vector equations for velocities are:

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

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

$$\left[T_{i-1}^{i}\right]=\begin{bmatrix}\left[D_{i-1}^{i}\right] & 0\\ -\left[D_{i-1}^{i}\right]\left[\widehat{r}_i^{i-1}\right] & \left[D_{i-1}^{i}\right]\end{bmatrix} \tag{2}$$

The matrix form of the dual absolute vector equations for accelerations are:

$$\begin{pmatrix}(\varepsilon_{i,0}^{i})\\ (a_{i,0}^{i})\end{pmatrix}=[T_{i-1}^{i}]\begin{pmatrix}(\varepsilon_{i-1,0}^{i-1})\\ (a_{i-1,0}^{i-1})\end{pmatrix}+(S''(i)) \tag{3}$$

$$(S''(i))=\begin{pmatrix}(\varepsilon_{i,i-1}^{i})+(\widehat{\omega}_{i-1,0}^{i})(\omega_{i,i-1}^{i})\\ (a_{i,i-1}^{i})+(\widehat{\omega}_{i-1,0}^{i})^2(r_{i,i-1}^{i})+2(\widehat{\omega}_{i-1,0}^{i})(v_{i,i-1}^{i})\end{pmatrix}$$

$$\begin{pmatrix}(\varepsilon_{i,0}^{0})\\ (a_{i,0}^{0})\end{pmatrix}=\begin{bmatrix}[D_i^0] & [0]\\ [0] & [D_i^0]\end{bmatrix}\begin{pmatrix}(\varepsilon_{i,0}^{i})\\ (a_{i,0}^{i})\end{pmatrix}$$

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

where: *(r^0_i)* is the column matrix vector for absolute position

i joint versus the base Cartesian system; $(r^0_{i\text{-}1})$- column matrix vector for absolute position i-1 joint; $[D^0_{i\text{-}1}]$- quadratic matrix for transfer vector from i-1 to base system; $\begin{pmatrix}(\omega^0_{i,0})\\(v^0_{i,0})\end{pmatrix}$ – is the dual matrix vector of the absolute angular and linear velocity of the i joint versus the Cartesian base system; $\begin{pmatrix}(\omega^i_{i,0})\\(v^i_{i,0})\end{pmatrix}$ - is the dual matrix vector of the absolute angular and linear velocity of the i joint versus the i Cartesian system; $\begin{pmatrix}(\varepsilon^i_{i,0})\\(a^i_{i,0})\end{pmatrix}$is the dual matrix vector of the absolute acceleration of the i joint versus the i Cartesian system; $\begin{pmatrix}(\varepsilon^0_{i,0})\\(a^0_{i,0})\end{pmatrix}$- the dual matrix vector of the absolute acceleration of the i joint versus the base Cartesian system; $\begin{pmatrix}(\varepsilon^{i-1}_{i-1,0})\\(a^{i-1}_{i-1,0})\end{pmatrix}$ - the dual matrix vector of the absolute acceleration of the i-1 joint versus the i-1 Cartesian system; $[T^i_{i-1}]$- the quadratic 6x6 transfer matrix from the i-1 to i system; $(S''(i))$- the dual matrix vector of the relative joint's acceleration between i and i-1 joints versus i Cartesian system; $(\varepsilon^i_{i,i-1})$- the column matrix vector of the relative angular acceleration between i and i-1 systems versus i Cartesian system; $(\widetilde{\omega}^i_{i-1,0})$- antisimetrical absolute vector of the angular velocity of the i-1 joint versus i Cartesian system; $(\omega^i_{i,i-1})$ - velocity angular relative column matrix vector between i and i-1 joints; $(a^i_{i,i-1})$ – linear relative acceleration column matrix form between i and i-1 joints versus i Cartesian system; $(\widetilde{\omega}^i_{i-1,0})^2(r^i_{i,i-1})$ - column matrix centrifuge relative acceleration between i and i-1 joints versus i Cartesian system; $2(\widetilde{\omega}^i_{i-1,0})(v^i_{i,i-1})$- column matrix form of the Coriolis relative acceleration between i and i-1 joints versus i Cartesian system; (r^0_i) is the column matrix vector for absolute position i joint versus the zero point; $(r^0_{i\text{-}1})$- column matrix vector for absolute position i-1 joint; $[D^0{}_{i\text{-}1}]$- quadratic matrix for transfer vector from i-1 to base system; i- the current robot's joint and have the 1-5 values.

Relations (2) contents the 6x6 matrix equation of the dual matrix vector of the absolute velocities reduced to the proper Cartesian system and determined by recursive calculus and the second relation is to transfer the velocities vector to the robot's base system. Relations (3) describe the dual matrix vector of the absolute acceleration reduced to the proper joints using the transfer 6x6 matrix between the Cartesian systems and the matrix relation to transfer the vectors to the robot's base system. Relation (4) define the 6x6 transfer matrix between all Cartesian systems.

A. Description of the Used LabVIEW Programs

The mathematical matrix model used in the assisted kinematic analyse of the robots was transposed in some virtual LabView instruments shown in Figs.3 and 4.

The front panel of the base program, Fig.4, contents the part for the input data for each robot's module and the results of simulation, the linear and angular velocities and acceleration characteristics and also the angular variation of the linear and angular velocity and acceleration in the 3D space.

The base program used the sub *VI*-s for the following actions: i) to determine all dual absolute velocity vector; ii) to generate the translation matrices between all Cartesian systems; iii) to generate all relative dual vectors of velocity and acceleration; iv) to generate the trapezoidal characteristics in each joints.

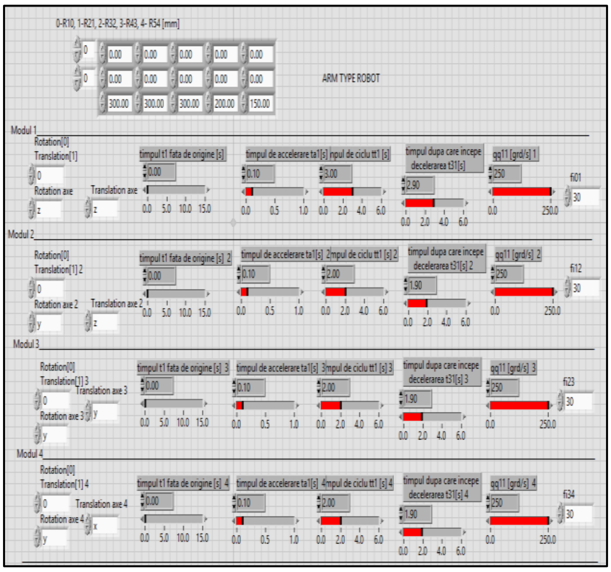


Fig. 4. The front panel of the LabVIEW program with input data

The theoretical assisted research with the proper LabView VI-s to determine the joint's positions, velocities and accelerations was done by using different types of movements. All these results are shown in the tables I and II. In the simulation activities, to be obtained good results and choose the better of them, we used the trapezoidal characteristics of relative velocities in all joints with combination between all movements like: simultaneously, successive, some successive and some simultaneously after acceleration time, some successive and some simultaneously after the constant velocity period, successive after the deceleration time, simultaneously with the same or different velocities values.

In all studied cases were shown the maximal variation of the linear and angular velocities and acceleration, the space angle between the base robot Cartesian system and the angular and linear velocity and acceleration of the end-effecter. All these could be influence the dynamic behaviour of the robot in different types of applications. The maximum variation of the angular or linear velocity and acceleration, the increasing of the frequencies variation, influence the force and moment in the joints determine the variation of the dynamic behaviour.

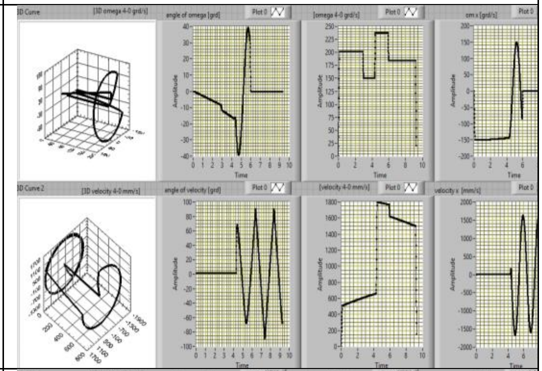
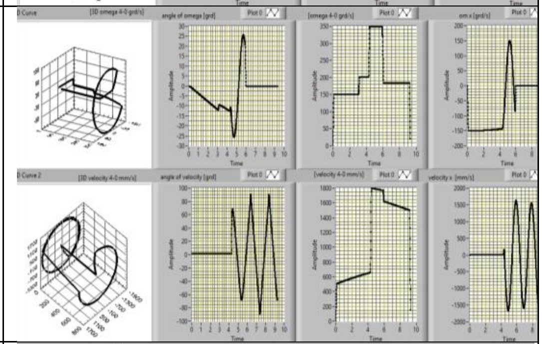
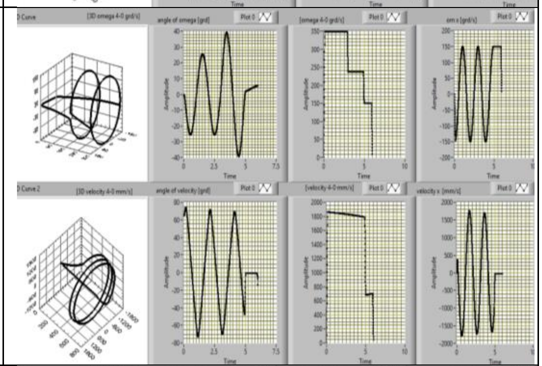
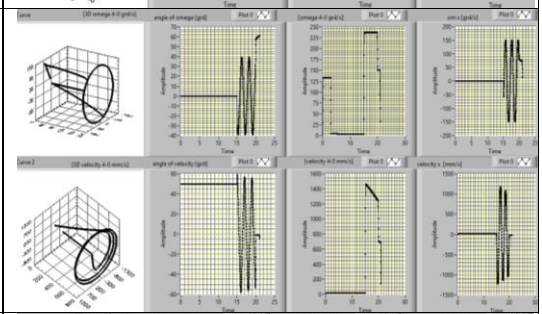
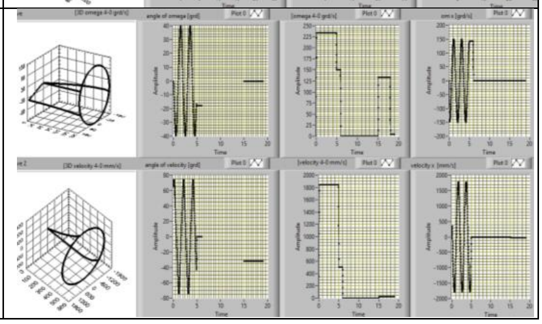
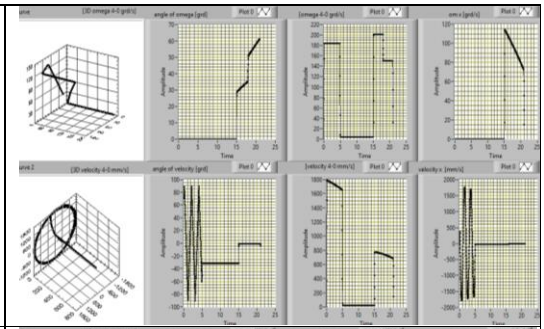
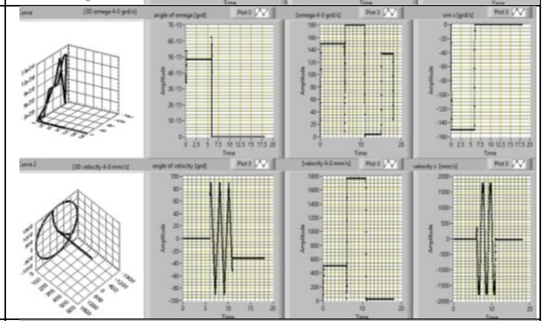
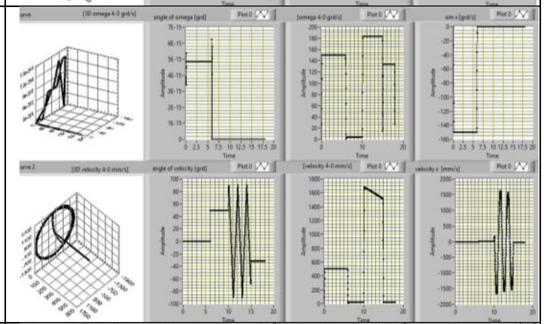
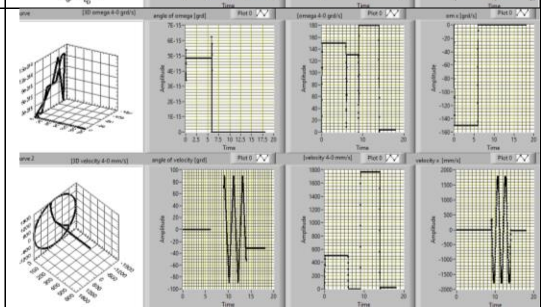
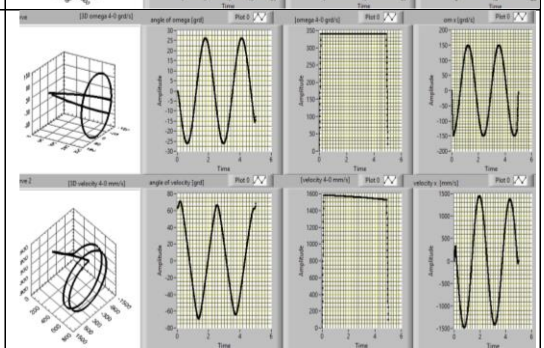
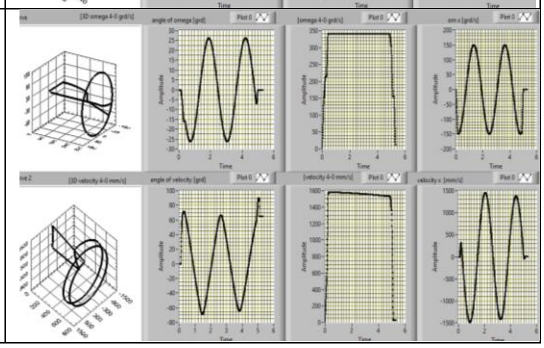
III. Results of the Simulation

After the simulation work were obtained the positions, velocities and accelerations variation versus time in the robot end effecter. Was study the Arm type robot with plan- parallel structure, fig.1. The cases were study contents the movement of the end-effecter in simultaneously, successive or combination between them.

A. Case Study of the Arm Type Robot with Plan-Parallel Str

The analyse will be done after study of the synthetic report presented in the Tables I and II.

TABLE I: 3D VARIATION OF THE OMEGA., LINEAR VELOCITY, ANGLE OMEGA, ANGLE VELOCITY

Case study	3D characteristics
0-0-0-0	
2-after 4.29s 4- after 3.05s	
0-0-0-0 with different cycle time	
15-15-0-0	
0-0-15-15	
0-15-0-15	
0-5-10-15	
0-10-5-15	
0-10-15-5	
0-0-0-0 150grd/s in all joints	
0-0.1-0.2-0.3	

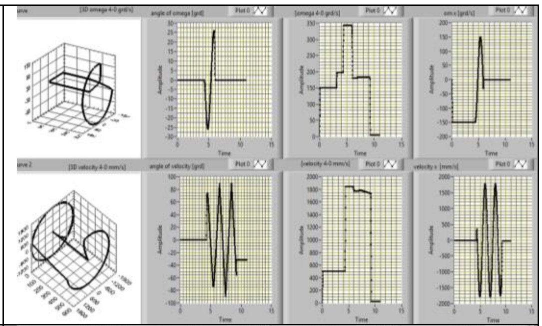
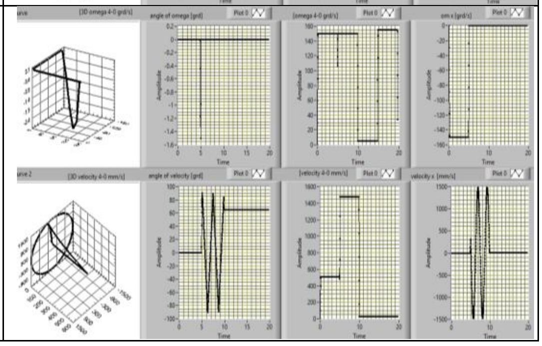
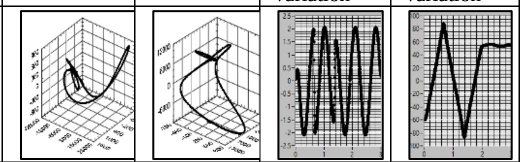
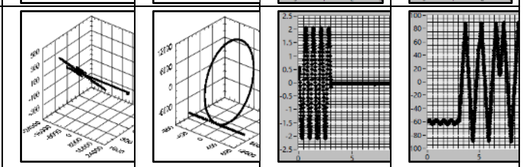
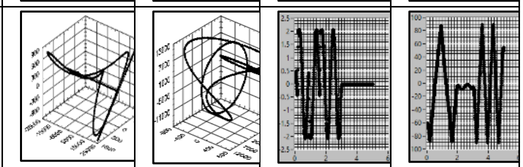
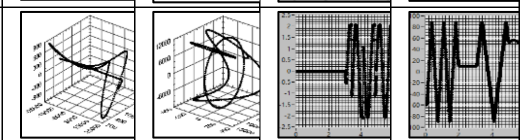
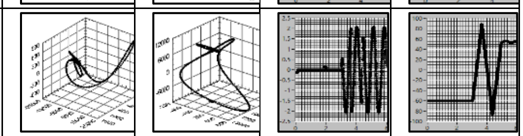
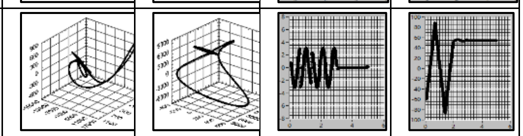
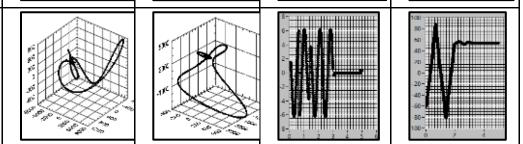
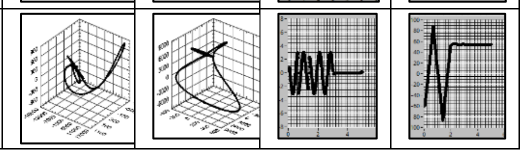
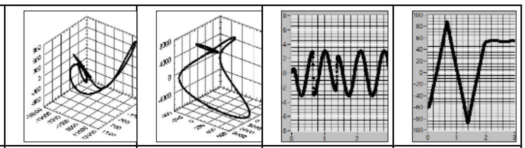
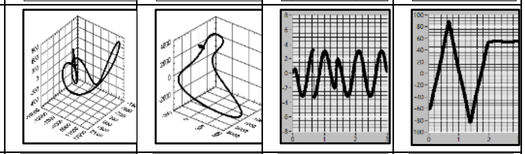
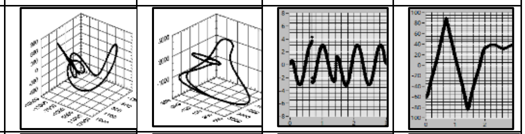
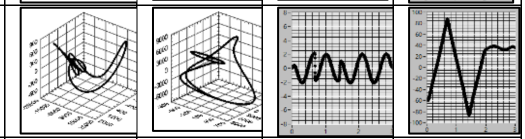
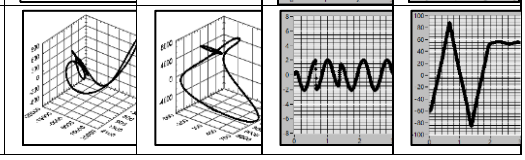
0-4.29-3.06-6.89	
0-4.9-9.9-14.9	

TABLE II: 3D VARIATION OF THE EPS., ACC., ANGLE EPS., ANGLE ACC

Case study	Eps. space variation	Acc. space variation	Eps. angle space variation	Acc. angle space variation
0-0-0-0				
0-2-4-6				
0-3-3-0				
3-0-0-3				
3-3-0-0				
0-0-3-3 L_i=300				
0-0-3-3 L_1=100				
0-0-3-3 L_i=200				
0-0-0-0 L_i=200 v_i=200				
0-0-0-0 L_i=100 200, 300, 400,100 v_i=200				
0-0-0-0 L_i=100, 200, 300, 400,100 v_i=250				
0-0-0-0 L_i=200, 300,300, 300,200 v_i=250				
0-0-0-0 L_i=200, 300,300, 300,200 v_i=250				

IV. ANALYSE OF THE ASSISTED RESULTS

After were analysed the results of the simulations, content in the table I and II, we can do the followings remarks: i) the complex analyse couldn't be done without virtual instrumentation LabVIEW especially created for this work; ii) some characteristics were compared with the experimental work, but not in all cases because the difficulty of data acquisitions; iii) the 3D characteristics of the velocity and acceleration offer one good perspective to the variation of the forces (especially Coriolis forces) and moments; iv) the movements studied cases in all robot's joints open the way to the optimization of the forces and moments variation by obtained the minimum of them; v) for the first time were studied the variation of the 3D space angular position of the velocity and acceleration end-effecter vectors; vi) the variation of these angular position of the linear and angular velocity and acceleration vectors in the space determine the same variation in the space of the forces and moments; vii) by using the maximal variation of all these vectors in the ox, oy and oz axes will pe possible to apply the pounder theory and choose the best solution for some robot application that impose some special requests; viii) the determined values of all modules of velocities and accelerations vectors will be calculated by the researchers all organology robot's parts.

V. CONCLUSION

The assisted research, proposed by this paper, with original contribution in modelling by 6x6 matrix form, and in the simulation with proper virtual LabVIEW platform for the assisted research of the position, velocity and acceleration, 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, multi robot application, or in the cooperation manner of them. Positions, velocities, accelerations and jerks are the most important components in the dynamic behaviour equations and by known these, will be possible to obtain the optimal kinematic robot's parameters and finally the goals in robotics: the maximal precision of the end-effecter. The presented matrix equations, the virtual LabView platform are generally and could be applying in many other robotic applications.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

AO conducted the research and all mathematical model, algorithm and wrote the paper; TD analysed the data and the English grammar; SO collected the data and analysed the English grammar; IM assured the experimental stand. All authors had approved the final version.

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References

[1] R. Zhao, "Trajectory planning and control for robot manipulations 2015 robotics," Université Paul Sabatier - Toulouse III. English NNT, 2015.

[2] T. Kroger and F. M. Wahl, "Online trajectory generation: Basic concepts for instantaneous reactions to unforeseen events," *Robotics IEEE*, vol. 26, no. 1, pp. 94–111, 2010.

[3] O. Dahl and L. Nielsen, "Torque-limited path following by online trajectory time scaling," *Robotics and Automation IEEE Transactions* vol. 6, no. 5, pp. 554–561, 1990.

[4] M. Brady, J. Hollerbach, T. Johnson, and T. Lozano-Perez, "Robot motion, planning and control," The MIT Press, Cambridge, Massachusetts, 1982.

[5] W. Khalil and E Dombre, "Modelisation, identification et commande des robots," *Hermes*, vol. 56, 1999.

[6] L. Biagiotti and C. Melchiorri, "Trajectory planning for automatic machines and robots," *Springer Science & Business Media*, 2008.

[7] D. Constantinescu and E. A. Croft, "Smooth and time-optimal trajectory planning for industrial manipulators along specified paths," *Journal of Robotic Systems*, vol. 17, no. 5, pp. 233–249, 2000.

[8] Z. Shiller, "Time-energy optimal control of articulated systems with geometric path constraints," in *Proc. Robotics and Automation IEEE Proceedings*, vol. 4, pp. 2680–2685, 1994.

[9] S. Liu, "An on-line reference-trajectory generator for smooth motion of impulse- controlled industrial manipulator," in *Proc. Advanced Motion Control 7th International Workshop*, pp. 365–370, 2002.

[10] W. S. Owen, E. A. Croft, and B. Benhabib, "Real-time trajectory resolution for dual robot machining," in *Proc. Robotics and Automation ICR'04 IEEE International Conference*, vol. 5, pp. 4332–4337, 2004.

[11] K. Ahn, W. K. Chung, and Y. Yourn, "Arbitrary states polynomial like trajectory (ASPOT) generation," in *Proc. Industrial Electronics Society 30th Annual Conference of IEEE IECON*, pp. 123–128, 2014.

[12] R. Haschke, E. Weitnauer, and H. Ritter, "On-line planning of time-optimal, jerk-limited trajectories," in *Proc. Intelligent Robots and Systems IROS 2008-IEEE/RSJ International Conference*, pp. 3248–3253, 2008.

[13] X. Broquere, D. Sidobre, and I. H. Aguilar, "Soft motion trajectory planner for service manipulator robot," in *Proc. Intelligent Robots and Systems IROS - IEEE/RSJ International Conference*, pp. 2808–2813, 2008.

[14] A. Olaru, S. Olaru, and N. Mihai, "Proper assisted research method solving of the robots inverse kinematics problem," *Applied Mechanics and Materials*, vol. 555, pp. 135-147, 2014.

[15] A. Olaru, "Theoretical and experimental research of cinematic and dynamic behaviour of industrial robots," in *Proc. Annals of DAAAM for 2001*, pp. 333-334, 2001.

[16] A. Olaru, S. Olaru, N. Mihai, and N. Smidova, "Neutrosophic theory applied in the multi objectives optimization of the robot's joints accelerations with the virtual LabVIEW instrumentation," *International Journal of Modeling and Optimization*, vol. 10, no. 3, pp. 79-85, 2020.

[17] A. D. Olaru, S. A. Olaru, N. C. Mihai, and N. M. Smidova. "Virtual instrumentation in the robot's kinematics velocities analyze," *International Journal of Modeling and Optimization*, vol. 9, no. 5, pp. 259-264, 2019.

[18] A. D. Olaru, S. A. Olaru, N. C. Mihai, and N. M. Smidova, "Assisted multi objectives research optimization of the arm type robot's forces," *International Journal of Modeling and Optimization*, vol. 10, no. 2, pp. 741-748, 2020.

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