Virtual Instrumentation in the Robot’s Kinematics: Velocities Analyze

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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 easy 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-effector 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-effector, 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.

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 derive 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-effector 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

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:

\[
\begin{bmatrix}
\rho_i^0 \\
\omega_i^0 \\
\nu_i^0 \\
\end{bmatrix} = \begin{bmatrix}
\rho_{i-1}^0 \\
\omega_{i-1}^0 \\
\nu_{i-1}^0 \\
\end{bmatrix} + \begin{bmatrix}
D_i^0 \\
0 \\
0 \\
\end{bmatrix} \begin{bmatrix}
\rho_{i-1}^1 \\
\omega_{i-1}^1 \\
\nu_{i-1}^1 \\
\end{bmatrix}
\]

(1)

\[
\begin{bmatrix}
\omega_i^0 \\
\nu_i^0 \\
\end{bmatrix} = [T_{i-1}] \begin{bmatrix}
\omega_{i-1}^0 \\
\nu_{i-1}^0 \\
\end{bmatrix} + \begin{bmatrix}
\omega_{i-1}^1 \\
\nu_{i-1}^1 \\
\end{bmatrix}
\]

(2)

\[
\begin{bmatrix}
\alpha_i^0 \\
\beta_i^0 \\
\end{bmatrix} = \begin{bmatrix}
D_i^0 & [0] \\
1 & [D_i^0] \\
\end{bmatrix} \begin{bmatrix}
\alpha_{i-1}^0 \\
\beta_{i-1}^0 \\
\end{bmatrix}
\]

(3)

\[
[T_{i-1}] = \begin{bmatrix}
D_{i-1} & 0 \\
-[D_{i-1}]^T & [D_{i-1}] \\
\end{bmatrix}
\]

(4)

\((\rho_i^0, \omega_i^0, \nu_i^0)\) is the column matrix vector for absolute position \(i\) joint versus the zero point; \((\rho_{i-1}^0, \omega_{i-1}^0, \nu_{i-1}^0)\)- column matrix vector for absolute position \(i-1\) joint; \([D_i^0, i-1]\)-quadratic matrix for transfer vector from \(i-1\) to \(i\)-base system;

where: \(\begin{bmatrix}
\omega_{i-1}^0 \\
\nu_{i-1}^0 \\
\end{bmatrix}\) is the dual matrix vector for absolute position \(i\) joint reduced to the \(i\) Cartesian System; \(\begin{bmatrix}
\omega_{i-1}^1 \\
\nu_{i-1}^1 \\
\end{bmatrix}\) - dual matrix vector for absolute velocity \(i-1\) joint reduced to the \(i\) Cartesian system; \([T_{i-1}]\)- quadratic matrix 6x6 for transfer dual vector from \(i-1\) to \(i\) Cartesian system;

\(\begin{bmatrix}
\omega_{i-1}^0 \\
\nu_{i-1}^0 \\
\end{bmatrix}\) - 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, minimal stationary errors of the space trajectory of the end-effector, 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.

The base program, Fig. 2, contains some sub VI-s that could be used in many other LabVIEW programs. The base program used the subVI-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 subVI-s to transform the data from the cluster to the matrix and the subVI-s to generate the trapezoidal characteristics of the relative velocity in all robot’s joints.

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

The front panels 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 $3\times3$ 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.

**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. 4. Front panel to construct the transfer matrices $T$ between cartesian systems.](image)

![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.](image)

![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.](image)

![Fig. 7. The results of the 3D angular and linear absolute velocities characteristics with simultaneously movements with different cycle times.](image)

![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.](image)
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-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 3-4, 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.

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 1 and 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 3-4, 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.
II. THE METHODS

The presented matrix equations, the algorithm, the virtual instrumentation are generally and they could be applying in many other robotic applications.

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