Mechanisms and Machine Science

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Advances in Asian Mechanism and Machine Science

Proceedings of IFToMM Asian MMS 2024

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Mechanisms and Machine Science 167

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Preface

The first conference on Asian Mechanism and Machine Science, in short Asian MMS, started in Taipei in 2010 as an initiative of IFToMM, the International Federation for the Promotion of Mechanism and Machine Science (MMS), as a specific forum for Asiatic communities to promote better relations and disseminations of MMS activities in Asia. Then, following events were held successfully in Tokyo in 2012, in Tianjin in 2014, in Guangzhou in 2016, in Bengaluru in 2018, and in Hanoi in 2021 in mixed teleconference and presential modes because of the COVID-19 pandemic. This year, the Asian MMS is organized in Kazakhstan by a very active IFToMM member organization. Once again, the conference has attracted a large number of researchers coming mainly but not only from Asia in a wide range of topics, within the spirit of collaboration of the IFToMM mission. This seventh event of Asian MMS is organized in Almaty during 28–30 August 2024 with a program for paper presentations thanks to the great effort of local organizers from U. Joldasbekov Institute of Mechanics and Engineering. The Asian MMS, although primarily intended for Asian countries, serves as a global platform for participants to exchange ideas and present their research work in the several fields of MMS in order to exchange and share new and innovative ideas. The papers in this proceedings volume were accepted after a peer review process and then they are presented in sessions of the conference which covers different topics on History and Education in MMS, Mechanism Design and Theory, Computational Methods, Machine and Robot Design, Gearing and Transmissions, Actuators and Sensors, Dynamics and Control of Multibody Systems, Vibration Techniques, Reliability, Biomechanics, Micro and Nano Systems, Experimental Methods in Mechanics, and Space Engineering and Technology . We have received 78 papers, of which 58 full papers were accepted after the review for presenting and being included in this proceedings volume together with four keynote contributions. The majority of the papers are from Kazakhstan, but submissions came also from other IFToMM communities such as China-Beijing, China-Taipei, India, Japan, Russia, Turkey, and even with collaboration from non-Asiatic countries. We express our grateful thanks to the members of International Scientific Committee for Asian MMS, for the support and promoting activities, namely Marco Ceccarelli (Italy) (Chair), Gondi Kondaiah Ananthasuresh (India), Yusuke Sugahara (Japan), Weizhong Guo (China-Beijing), Yu-Hsun Chen (China-Taipei), Khang Nguyen Van (Vietnam), Erkin Gezgin (Turkey), Jomartov Assylbek (Kazakhstan). We would like to express our sincere gratitude to the reviewers, who contributed to the review process with their experience and expertise in due time with a speedy but rigorous review process. The authors of the papers are also acknowledged for having finalized the papers submission after careful revision according to the review comments. We believe that the published papers can be of interest and stimulus for readers for their future activity also with the aim to contribute with their results to the next events of the Asian MMS. We would like to thank all the team members of the organizing committee at the U. Joldasbekov Institute of Mechanics and Engineering in Almaty, who helped with the conference organization and preparation of these proceedings. We would like to send our also appreciation to the Springer-Nature team for their support and patience in publishing this book in time for Asian MMS conference.

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Contents

3D Modeling Manipulator Movement and Direct Positional Kinematic Analysis

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Abstract. Computer 3D modeling of any robotic system has become widespread in the last few years and is used for educational and research purposes. Currently, there are lots of 3D modeling tools available for various fields of robotics research with some advantages and limitations. In this paper, as an example a computer model of the RRRRT manipulator and its movement. To create a 3D model of the manipulator, at first, you need to obtain 3D models of the manipulator components: kinematic pairs, links, grips, etc. in the Maple environment. Next, it is necessary to combine all the parts of the manipulator into one system using the developed program in the Maple environment, while specifying the main connections between them to create a full-fledged visualized moving model of the manipulator. Also, in this paper, the direct positional kinematics problem of this manipulator is studied in detail. To find the kinematic characteristics of the manipulator, the Denavit-Hartenberg and Newton-Euler methods were rationally used. The received results are presented in the form of 3D graphs. Such graphs allow you to visually observe how the modules and directions of the given parameters of the manipulator change in the graph, depending on the manipulator position in space.

Keywords: computer modeling · kinematics · positional problem · 3D model · manipulators · Maple

1 Introduction

Computer 3D modeling of manipulators is one of the most promising directions in the spatial mechanisms studies [1]. Since with the increasing complexity of the designed systems, while their analytical study becomes more difficult, the creation of prototypes costs more expensive, the modeling of spatial manipulators on a computer often turns out to be the leading or even the only available research method [2].

Modeling the spatial manipulators movement even in a kinematic formulation is a complex mathematical task. Using the software packages that work with the construction of three-dimensional models, the creation of objects of any complexity is a painstaking, but solvable task [3].

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To create a 3D model of a spatial manipulator can be used CAD systems such as SimMechanics, Autodesk Inventor, SolidWorks, Adams and software environments Matlab, Maple, etc. [4].

This paper focuses on developing algorithms and programs for creating spatial motional 3D models and solving forward positional kinematics of this 3D models of manipulators in the same program environment. Kinematics are determined by implementing Denavit-Hartenberg, Newton-Euler, and analytical methods. The 3D motional model of manipulator is generated in the Maple math environment. The highlights of this paper are that the created algorithms and program provide building different 3D model of manipulators which can move and is controlled by generalized coordinates. Furthermore, analytical method provides the most accurate outcomes compared to other methods and offers an opportunity to receive generalized characteristics during the design process. Building a 3D model of manipulator movement and solving kinematics in a single Maple programming environment is a more convenient, affordable, and productive way to conduct research, and results are given in the form of 3D graphs. Such graphs allow for visual observation of how the modules and directions of the given manipulator parameters change in the graph, depending on the manipulator's position in space.

2 Computer 3d Modeling of Spatial Manipulators

Modeling and assembly of links and connections of manipulators were performed using operators of the Maple software environment. Maple has lots of possibilities for creating a moving 3D model and demonstrating the movement of each link from all sides of the manipulators in space, as well as conducting kinematic and dynamic analysis in the same program, showing any changes and results.

In this section, as an example of this research was taken RRRRT manipulator with five degrees of freedom, four rotational and one translational, which might be implemented in almost all spheres manufacturing, engineering and so on.

Because of the axes of kinematic links are mutually perpendicular and parallel, it is available to use the method of constructing a coordinate system proposed by J. Denavit and R. Hartenberg in the formation of coordinate manipulator links systems. To create a full-fledged visualized moving manipulator model with the given laws of generalized coordinates of a manipulator, it is necessary to combine all parts of the manipulator into one system using programs in the Maple environment, while specifying the main connections between them.

For kinematic analysis and building a model of spatial mechanisms, it is necessary at first to form coordinate systems of the manipulator links. The formed coordinate systems of the RRRRT manipulator's links are shown in Fig. 1. Secondly, it is necessary to construct the parameters of kinematic pairs of the manipulator under study. These parameters for the RRRRT manipulator are represented in Table 1.

Table 1. Parameters of kinematic pairs for the RRRRT manipulator

Kinematic pairs	Links forming kinematic pairs	Types of kinematic pairs	The value of the parameters			
			θ_i	d_i	a_i	α_i
1	0,1	rotational	θ_1	0.85	0	$\frac{\pi}{2}$
2	1,2	rotational	θ_2	−0.09	0.85	0
3	2,3	rotational	θ_3	−0.09	0	$-\frac{\pi}{2}$
4	3,4	rotational	θ_4	0.85	0	0
5	4,5	translational	0	d_5	0	0

According to Table 1, we can observe that the generalized coordinates of the RRRRT manipulator are the following parameters: $\theta_1, \theta_2, \theta_3, \theta_4, d_5$.

3 A Forward Positional Kinematics Solution of Spatial Manipulators

In this section, the forward positional kinematics problem of this spatial manipulator is studied in detail. To find the kinematic characteristics of the manipulator, the Denavit-Hartenberg and Newton-Euler methods were rationally implemented. Received matrix, equations of linear and angular velocity, acceleration was solved by analytical method using Maple environment.

A special choice of coordinate systems of the manipulator links allows using only four parameters (not six, as in the general case) to describe the transition from one system to another. The system $O_{i-1}X_{i-1}Y_{i-1}Z_{i-1}$ can be transformed into the system $O_iX_iY_iZ_i$ by means of rotation, two transfers and one more rotation.

The resulting transition matrix connecting the systems $O_{i-1}X_{i-1}Y_{i-1}Z_{i-1}$ and $O_iX_iY_iZ_i$ is the product of the above matrices:

$$A_i^{i-1} = R(Z_{i-1}, \theta_i)T(Z_{i-1}, s_i)T(X_{i-1}, a_i)R(X_i, \alpha_i) \tag{1}$$

The matrix A_i^{i-1} is written in the following form.

$$A_i^{i-1} = \begin{bmatrix} R_i^{i-1} & \vec{O}_i^{i-1} \\ 0 & 1 \end{bmatrix}, \tag{2}$$

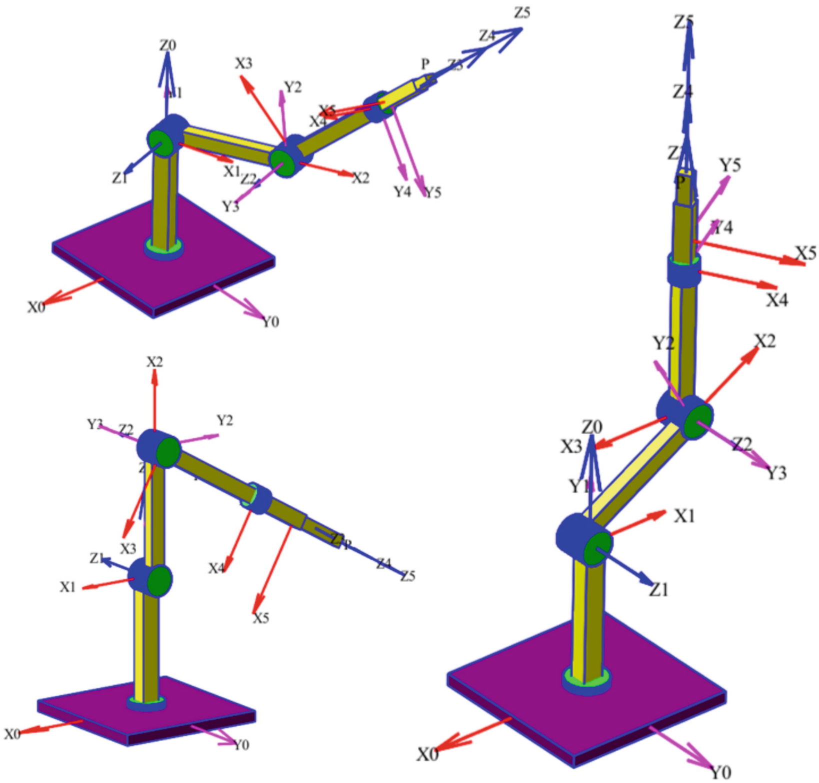

Fig. 1. 3D motional model of the RRRRT manipulator in several positions

The position and orientation of the i-th link of the manipulator in the reference frame $O_0X_0Y_0Z_0$ associated with the rack is determined as follows [5]:

$$A_i^0 = A_1^0 A_2^1 A_3^2 \ldots A_i^{i-1} = \begin{bmatrix} R_i^0 & \overrightarrow{O}_i^0 \\ 0 & 1 \end{bmatrix}. \tag{3}$$

The angular velocity $\overrightarrow{\omega}_i$ of the i-th link relative to the base coordinate system is represented as follows [17]:

$$\overrightarrow{\omega}_i = \begin{cases} \overrightarrow{\omega}_{i-1} + R_{i-1}^0 \overrightarrow{z}_0 \dot{q}_i, \text{ if the } i - \text{th kinematic pair is rotational,} \\ \overrightarrow{\omega}_{i-1}, \text{ if the } i - \text{th kinematic pair is translational,} \end{cases} \tag{4}$$

Then the angular acceleration $\overrightarrow{\varepsilon}_i$ of the i-th link relative to the base coordinate system is determined by the expression:

$$\vec{\varepsilon}_i = \begin{cases} \vec{\varepsilon}_i = \vec{\varepsilon}_{i-1} + R_{i-1}^0 \vec{z}_0 \ddot{q}_i + \vec{\omega}_{i-1} \times \left(R_{i-1}^0 \vec{z}_0 \dot{q}_i \right), \\ \text{if the } i - \text{th kinematic pair is rotational,} \\ \vec{\varepsilon}_{i-1}, \text{ if the } i - \text{th kinematic pair is translational.} \end{cases} \tag{5}$$

For linear velocities and accelerations of the *i*-th link of the manipulator relative to the base coordinate system we have the following relations:

$$\vec{v}_i = \begin{cases} \vec{v}_{i-1} + \vec{\omega}_i \times \vec{p}_i^{\,i-1}, \text{ if the } i-\text{th kinematic pair is rotational,} \\ \vec{v}_{i-1} + \vec{\omega}_i \times \vec{p}_i^{\,i-1} + R_{i-1}^{0}\vec{z}_0\dot{q}_i, \\ \text{if the i} - \text{th kinematic pair is translational.} \end{cases} \quad (6)$$

$$\vec{a}_i = \begin{cases} \vec{a}_{i-1} + \vec{\omega}_i \times \left(\vec{\omega}_i \times \vec{p}_i^{\,i-1}\right) + \vec{\varepsilon}_i \times \vec{p}_i^{\,i-1}, \\ \text{if the } i-\text{th kinematic pair is rotational,} \\ \vec{a}_{i-1} + \vec{\omega}_i \times \left(\vec{\omega}_i \times \vec{p}_i^{\,i-1}\right) + 2\vec{\omega}_i \times (R_{i-1}^{0}\vec{z}_0\dot{q}_i) + \vec{\varepsilon}_i \times \vec{p}_i^{\,i-1} + R_{i-1}^{0}\vec{z}_0\ddot{q}_i, \\ \text{if the i} - \text{th kinematic pair is translational.} \end{cases} \quad (7)$$

Linear velocities and acceleration of the point $\overrightarrow{P}_i^{\,i} = [x_i\ y_i\ z_i]^T$ of the *i*-th link, respectively, relative to the base coordinate system are determined by the expressions:

$$\overrightarrow{v}_{iP} = \overrightarrow{\omega}_i \times \overrightarrow{P}_i + \overrightarrow{v}_i, \quad (8)$$

$$\overrightarrow{a}_{iP} = \overrightarrow{a}_i + \overrightarrow{\omega}_i \times \left(\overrightarrow{\omega}_i \times \overrightarrow{P}_i\right) + \overrightarrow{\varepsilon}_i \times \overrightarrow{P}_i. \quad (9)$$

Analytical method solving kinematics of manipulators is different from another mostly implemented methods in that it supplies exact outcomes and clearly demonstrates mathematical model of the phenomenon. As for using Maple math environment for 3D modeling, solving forward kinematic problem of manipulators, and illustrating obtained result in the form of 3D graphs could be convenient way because of performing almost all mentioned actions in the same program.

4 Results and Discussion

Figures 2, 3, 4, 5, 6, 7 below demonstrate the results received in Maple 2021 of kinematic analysis in the form of 3d graphs of the RRRRT manipulator some kinematic characteristics for 36 positions relative to a fixed coordinate system$O_0X_0Y_0Z_0$, with the following specified values of generalized coordinates: $\theta_1 = 2\pi\sin\left(\frac{\pi}{2k} * i\right)$, $\theta_2 = -\frac{\pi}{6} + \frac{2\pi}{3}\sin\left(\frac{\pi}{2k} * i\right), \theta_3 = -\frac{\pi}{2} + \frac{2\pi}{3}\sin\left(\frac{\pi}{2k} * i\right), \theta_4 = \frac{2\pi}{k} * i, d_5 = 0.35 * \sin\left(\frac{\pi}{2k} * i\right)$, where k = 36, i = 0..36.

The point P of the RRRRT manipulator is connected to the coordinate system $O_5X_5Y_5Z_5$ and relatively in this system has coordinates $P_5 = [000.35]^T$. The red line in the figures is the trajectory of a point or the hodographs of angular and linear accelerations relative to the base coordinate system $O_0X_0Y_0Z_0$. Yellow and green straight lines with an arrow are vectors connecting the points of the trajectory or hodograph with the beginning of the base coordinate system.

To verify our developed algorithms and programs, we applied it to solving problems, using as an example the created 3D moving model of the RRRRT manipulator. The forward positional kinematics problem was solved and diagrams of changes in angular and linear accelerations were constructed. Thus, we wanted to show that the algorithms

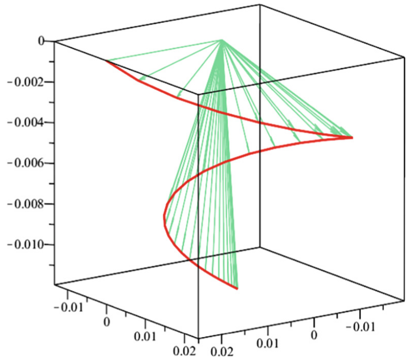

Fig. 2. Angular acceleration ε_2 of link 2 for 36 positions of the manipulator RRRRT

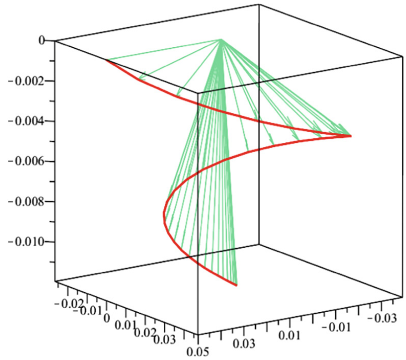

Fig. 3. Angular acceleration ε_3 of link 3 for 36 positions of the manipulator RRRRT

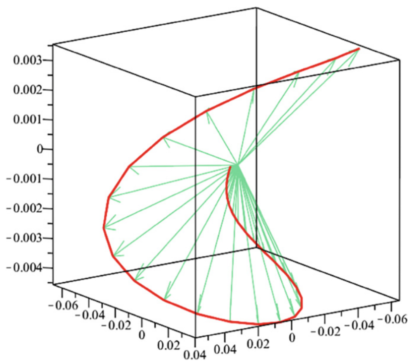

Fig. 4. Linear acceleration a_{O2} of the origin O_2 of the moving coordinate system $O_2X_2Y_2Z_2$ for 36 positions of the RRRRT manipulator

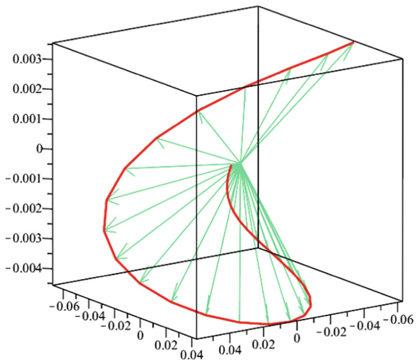

Fig. 5. Linear acceleration a_{O3} of the origin O_3 of the moving coordinate system $O_3X_3Y_3Z_3$ for 36 positions of the RRT manipulator

and programs developed by us work, and to determine angular and linear accelerations does not depend on how the position of the mechanism changes.

In this study, the vectors of linear accelerations of points and the vectors of angular accelerations of the links of this spatial manipulator were determined relative to the base and associated Denavit-Hartenberg coordinate systems using the Newton-Euler recurrent equations. The components of these vectors were ascertained for subsequent investigations. This step is crucial as it forms the basis for comprehending various dynamic loads and discerning the underlying distribution patterns.

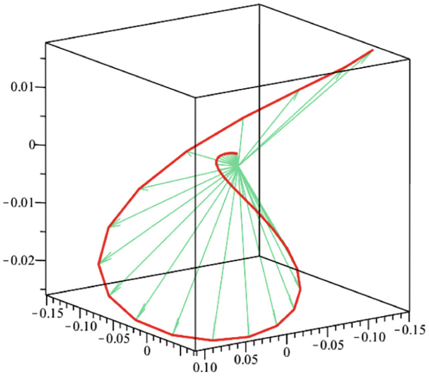

Fig. 6. Linear acceleration a_{O4} of the origin O_4 of the moving coordinate system $O_4X_4Y_4Z_4$ for 36 positions of the RRT manipulator.

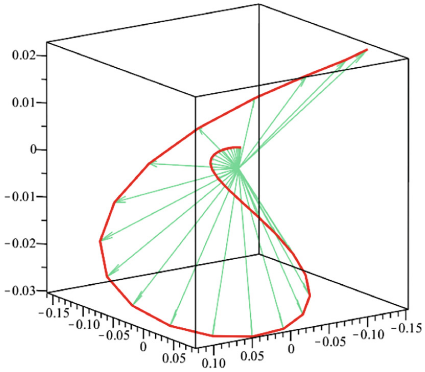

Fig. 7. Linear acceleration a_{O5} of the origin O_5 of the moving coordinate system $O_5X_5Y_5Z_5$ for 36 positions of the RRRRT manipulator

5 Conclusion

In this research, it is proposed a methodology for creating a 3d model of manipulators and their movement in the Maple environment. It describes simple and understandable methods for creating any three-dimensional virtual model of manipulators for motion modeling and various types of analysis. It is presented modeled RRRRT manipulator and is solved the direct positional kinematics problem of this manipulator, the received results of kinematic characteristics are illustrated in three-dimensional graphs. Using of the developed technique, you can quickly model any other three-dimensional manipulator.

Furthermore, the significance of the research is accentuated by the implementation of these algorithms and programs within only the Maple environment. Here, a comprehensive study encompassing kinematics, dynamics, and force analysis can be undertaken, with the resulting insights directly visualized on the manipulators. It is anticipated that this work will serve as a catalyst for further investigations and adaptations of the presented algorithms and programs to a broader range of analytical domains.

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