University POLITEHNICA of Bucharest

SCIENTIFIC BULLETIN

Series D: Mechanical Engineering

Volume 75 Issue 3 2013

editura
POLITEHNICA
PRESS

ISSN 1454 – 2358

University POLITEHNICA of Bucharest

SCIENTIFIC BULLETIN

founded in 1929

SERIES D: Mechanical Engineering

Volume 75 Issue 3 2013

This issue appears thanks to the carefull supervision of *prof.* Ştefan PASTRAMA and *prof.* Ştefan STAICU.

Contents

原书缺页

原书缺页

U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 3, 2013 ISSN 1454-2358

GREAT ROMANIAN PERSONALITIES IN MECHANISM AND MACHINE THEORY

In the XIXth century the first engineering schools were created in Romania. *School of Gheorghe Asachi* in Iassy (1813) and "*Şcoala Academicească pentru Ştiinţe Filosoficeşti şi Matematiceşti*" of Gheorghe Lazar in Bucharest (1818) gave the first engineers trained in Romanian language and graduated in 1818 .

During the XXth important contributions in engineering field and also in TMM field were achieved, this paper being a tribute to the scientific Romanian personalities.

Academician Radu P. Voinea – an outstanding personality of the University POLITEHNICA of Buchareast

Radu Voinea (1923-2010) was a professor at the University "Politehnica" of Bucharest and at the Civil Engineering Institute of Bucharest. He is a scientific personality internationally recognized as a member of several European Academies. He was the general secretary of Romanian Academy (1967-1974), the president of Romanian Academy (1984-1990) and the chairman of the Romanian Academy Technical Sciences Department (1991-1993, 1998-2000).
He is the Doctor Honoris Causa of thirteen universities .
His handbook "Theoretical Mechanics" published in three editions (1958, 1963, 1968) and written in collaboration with Victor Vilcovici and Stefan Balan is one of the most complete books, which includes the fundamental and applicative notions in mechanics.
The academician Radu P. Voinea had a rich scientific activity.
He is widely recognized in the field of mechanisms theory by the scientific world for his following papers: *The analysis of mechanisms over-constrained, Kinematic chains over-constrained, Screw axes and spatial mobility mechanisms, Complexity and mobility of mechanisms*. His innovative ideas and their priority are mentioned by K.J. Waldron (*The Constraint Analysis of Mechanisms*, J. Mech, 1996) and KH Hunt and J.R. Phillips (*Zur Kinematik Mechanischer Verbindungen für räumliche Bewegungen*, Wiss. Z.Tech. Hochschule Karl-Max-Stadt, 1965).
Radu P. Voinea also developed a general method for the synthesis of kinematic pairs in "*A General Method for Kinematic Synthesis Pairs*" published in The Scientific Journal of IFToMM, Pergamon Press, 1995.

Professor Nicolae I. Manolescu – a founder of the Romanian school of Mechanisms and Machines Theory

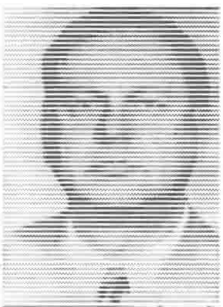
Nicolae I. Manolescu (1907-1993) was a professor at the University "Politehnica" of Bucharest (UPB). He was the Dean of Faculty of Transport at UPB (1959-1972) and the Head of the Department of Mechanisms and Machines Theory (1962-1973).
In UPB professor Manolescu and his colleagues give a great importance to mechanisms design and practical applications of the theory of mechanisms and machines.
The handbook *Theory of Mechanisms and Machines* written by N.I. Manolescu, Fr. Kovacs and A. Oranescu is a large synthesis in the field of mechanisms and machines theory.
Nicolae I. Manolescu, member of the Romanian Academy has major contributions to the structure of mechanisms.
Prof.dr.doc.eng. Nicolae I. Manolescu work is recognized for the general methods of the planar linkages and mechanisms structural analysis and synthesis in the Romanian mechanisms school. His work includes four methods to generate planar kinematic chains.
Professor N.I. Manolescu works summarizes four methods to generate planar kinematic chains, developed and published the first three.
Professor Manolescu was a founder member of IFToMM and a member of the Permanent Commission for the Standardization of Terminology. He was the president of the Romanian Association for TMM – ARoTMM – IFToMM, a Honorary Member of the Technical Committee of Mechanisms with Bars and Cams, a Honorary Member of the Editorial Board of the journal "Mechanism and Machine Theory", a member of Bulletin Editorial Committee of the Polytechnic Institute Bucharest. He was also a member of the Romanian Association of Robotics and the Tensometry Association .

Academician Dumitru Mangeron – a founder of research schools

An emblematic example for the scientific activity can be considered the work done by academician Dumitru Mangeron. He was professor at Universities "Alexandru Ioan Cuza" and "Gheorghe Asachi" of Iassy.
Professor Mangeron (1906-1991) is famous for his work in Mathematics, Mechanisms, Astronomy and Celestial Mechanics being a member of several scientific societies and also of international editorial boards.

Moreover in Mathematics he found Mangeron polyvalent equations, Mangeron interpolated operators, Mangeron theorems, Mangeron equations. He published papers in the history of mathematics.
The academician Dumitru Mangeron had a scientific activity about 61 years. During this period he founded scientific research schools, developed a rich scientific activities in different areas as mathematics, mechanics and mechanisms theory.
His scientific contributions are related to the technical requirements. He has significant papers on theory of partial differential equations, analytical mechanics, theory of mechanisms, optimization theory, theory of low accelerations and higher order accelerations, many of them published in prestigious international journals. He published, single author or in collaboration over 600 scientifically papers [1].
The professor was a member on international editorial board to *Journal de Mécanique appliquée (*France), to *Mechanism and Machine Theory (USA), to International Mathematical News (*Vienna) and to *European Journal of Mechanics. He also was a member in the managerial board on Revue Roumaine des Sciences Téchniques*, *série de Mécanique appliqué*. He was also the member of *American Society of Mechanical Engineering* (ASME).

Professor Christian Pelecudi – a remarkable researcher and professor



Christian Pelecudi (1922-1991) was a professor at the University Politehnica of Bucharest in the Mechanisms and Machines Theory Department and a scientific researcher at the Institute of Solid Mechanics of the Romanian Academy.
Prof.dr.doc. eng Christian Pelecudi is recognized as an engineer and a scientist.
He became in 1975 the vice president of the International Federation for Promotion of Mechanism and Machine Science (IFToMM) and the first president of the Romanian Association of Robotics. In October 1976 at the IInd Symposium of Mechanisms and Mechanical Transmissions he presented the first paper in the robotics field in Romanian entitled "*Introduction to robotics*".
Prof. dr. doc. Christian Pelecudi, a scientific personality nationally and internationally recognized is the founder of Robotics in our country. The first curricula in Robotics are created by him. He also delivered lectures in the robots field and promoted the scientific researches.
He was the creator of the first research and design centre in Robotics entitled MEROTEHNICA and the initiator of the first national symposium of industrial robots.

He carried out an intense scientific activity reflected in publications and hid attendance at the national and international scientific congresses and meetings. Some of the most important books published by Professor Christian are *The mechanism analysis bases* (1967), Theory *of spatial mechanisms* (1972), *The precision of mechanisms* (1975).

Professor Desideriu Maros – a scientific personality of the Technical University of Cluj Napoca

Desideriu Maros (1920-2011) was a professor at the Technical University of Cluj Napoca.
He is recognized as a scientist and a researcher in mechanical engineering.
He was a member of several European Associations, member of IFToMM, member of Société d'Études de l'Industrie de l'Engrenage (S.E.I.E.) France and member of Gesellschaft für Angewandte Mathematik und Mechanik (G.A.M.M.) Germany.
The most important fields in which professor Maros is known are the theory of machines and mechanisms, especially in the gearing theory and worm gears.
There are mentioned the following published books: Kinetostatics and Dynamics (Manolescu, N.I., Maros,D., 1958), Kinematics of Gears (1958), Mechanisms Notes (Maros, D., 1964), Worm gears (Maros, D., Killimann, V., Rohonyi, V., 1966), Mechanisms (Maros, D., 1980) and *Mechanisms* (Pelecudi, Chr., Maros, D., Merticaru, V., Pandrea, N., Simionescu, I., 1985).
For his entire activity Desideriu Maros was awarded by the title of "Honorary Citizen" of Cluj-Napoca and Doctor Honoris Causa of the Technical University of Cluj-Napoca (2001) and of Transilvania University of Brasov (2005).
He obtained the Gold Diploma (1993) and Diamond Diploma (2003) of the University of Technology and Economics at Budapest, Honorary Diploma of Robotics Association in Romania (1998), Excellence Diploma of the Technical University of Cluj-Napoca at the Ninth International Conference on Mechanisms and Mechanical Transmissions (2004) [13].

Professor Radu C. Bogdan – a scientific researcher and diplomat

Radu C. Bogdan (1923-2004) was a professor at the Institute of Oil, Gas and Geology Bucharest, at Transylvania University of Brasov and the University „Politehnica" of Bucharest.
He was the author of remarkable books and scientific papers.
His most important books "Complex harmonic and mechanic-electrical analysis of planar mechanisms" (Bogdan, R.,

Larionescu, D.) and "The synthesis of articulated planar mechanisms" (Bogdan, R., Larionescu, D., Cononovici, S.) are published at the Romanian Academy Publishing House.
Professor Bogdan was a deputy of Minister of Education (1974-1979), a deputy scientific director of Center of Solid Mechanics of the Romanian Academy, Rector of Transylvania University of Brasov (1977-1981), Romanian ambassador in Japan (1981-1988).
He also served as general secretary of the Romanian National Committee of Applied Mechanics, as vice president of the National Committee of Theory of mechanisms and machines in the CNIT, was member in the Central Council ASTT.

Professor Francisc Viliam Kovacs – a founder of the robotics school at the University Politehnica of Timisoara

Francisc Viliam Kovacs was a professor at the University Politehnica of Timisoara. He was the head of the Department of Machine Parts and Mechanisms (1970-1976 and 1984-1995). During the period 1976-1984 professor Kovacs was the dean of the Faculty of Mechanical Engineering.
Professor Kovacs was a founder of Robotics at University „Politehnica" of Timisoara. He held courses in robotics field at Oradea University, University "Aurel Vlaicu" of Arad and at University "Eftimie Murgu" of Reşiţa.
Professor Kovacs and Professor Muresan organized and developed a strong research – design multidisciplinary team in 1979.
Professor Christian Pelecudi from University Politehnica of Bucharest and professor Francisc Viliam Kovacs organized and founded the Robotics Society of Romania in 1990.
He had a great reputation as an engineer and scientist. He carried out an intense scientific activity reflected in publications in the country and abroad and his attendance at many national and international scientific congresses.
He published with his collaborators over 270 scientifically papers in the robots and mechanism fields. He was a Doctor Honoris Causa of the Craiova University, Oradea University, University "Eftimie Murgu" of Reşiţa. He received awards, honors, degrees and diplomas from the academic institutions of Romania and abroad.
Professor Francisc Kovacs was a member of some scientific societies: International Federation of Robotics, IFToMM and Public Corporation of the Hungarian Academy of Sciences.

This paper is a short overview of the Romanian outstanding books and papers on TMM published in the XXth century. The Romanian universities are recognized in the world for their continuous theoretical and practical activities developed for the promotion of mechanism and machine science.

Authors: Lecturer Ileana DUGĂEŞESCU[1], Professor Adriana COMĂNESCU[2], Professor Marco CECCARELLI[3] and Professor Marin BICĂ[4]

[1] Lecturer, Department of Machines and Mechanisms Theory, University POLITEHNICA of Bucharest, Romania, e-mail: ileana_d1@yahoo.com
[2] Prof., of Machines and Mechanisms Theory, University POLITEHNICA of Bucharest, Romania, e-mail: adrianacomanescu@yahoo.com
[3] Prof., LARM: Laboratory of Robotics and Mechatronics, DICEM, University of Cassino and South Latium, Italy, e-mail: ceccarelli@unicas.it
[4] Prof., Department of Applied Mechanics and Civil Constructions, România, University of Craiova, Department of Applied Mechanics and Civil Constructions, Romania

U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 3, 2013 ISSN 1454-2358

KINEMATICS OF THE SPATIAL 3-*UPU* PARALLEL ROBOT

Stefan STAICU[1], Constantin POPA[2]

Recursive matrix relations for kinematics analysis of a parallel manipulator, namely the universal-prismatic-universal (3-UPU) robot, are established in this paper. Knowing the translational motion of the platform, the inverse kinematics problem is solved based on the connectivity relations. Finally, some simulation graphs for the input displacements, velocities and accelerations are obtained.

Keywords: Connectivity relations; kinematics, parallel robot

1. Introduction

Parallel robots are closed-loop structures presenting very good potential in terms of accuracy, stiffness and ability to manipulate large loads. One of the main bodies of the mechanism is fixed and is called *the base*, while the other is regarded as movable and hence is called *the moving platform* of the manipulator. Generally, the number of actuators is typically equal to the number of degrees of freedom and each leg is controlled at or near the fixed base [1].

Compared with traditional serial manipulators, the following are the potential advantages of parallel architectures: higher kinematical accuracy, lighter weight and better structural stiffness, stable capacity and suitable position of actuator's arrangement, low manufacturing cost and better payload carrying ability. Accuracy and precision in the direction of the tasks are essential since the positioning errors of the tool could end in costly damage [2].

Important efforts have been devoted to the kinematics and dynamic investigations of parallel robots. Among these, the class of manipulators known as Stewart-Gough platform, used in flight simulators, focused great attention (Stewart [3]; Di Gregorio and Parenti Castelli [4]). The prototype of the Delta parallel robot developed by Clavel [5] at the Federal Polytechnic Institute of Lausanne and by Tsai and Stamper [6] at the University of Maryland, as well as the Star parallel manipulator (Hervé and Sparacino [7]), are equipped with three motors, which train on the mobile platform in a three-degrees-of-freedom general translational motion. Angeles [8], Wang and Gosselin [9] analysed the kinematics, dynamics and singularity loci of Agile Wrist spherical robot with three revolute

[1] Professor, Department of Mechanics, University POLITEHNICA of Bucharest, ROMANIA
[2] Lecturer, Department of Mechanics, University POLITEHNICA of Bucharest, ROMANIA

actuators. In the previous works of Li and Xu [10], [11], the 3-PRC and 3-PUU spatial parallel kinematical machines with relatively simple structure were presented with their kinematics solved in details.

In the present paper, a recursive matrix method, already implemented in the inverse kinematics of parallel robots, is applied to the inverse analysis of a spatial 3-DOF mechanism. It has been proved that the number of equations and computational operations reduces significantly by using a set of matrices for kinematics modelling.

2. Kinematics analysis

The 3-*UPU* architecture parallel manipulators are already well known in the mechanism community. The manipulator consists of a fixed base $A_1B_1C_1$, a circular mobile platform $A_5B_5C_5$ and three extensible legs with identical kinematical structure. Each limb connects the fixed base to the moving platform by two universal (*U*) joints interconnected through a prismatic (*P*) joint made up of a cylinder and a piston. Hydraulic or pneumatic systems can be used to vary the lengths of the prismatic joints and to control the location of the platform (Fig. 1).

Since each *U* joint consists of two intersecting revolute (*R*) joints, each leg is equivalent to a *RRPRR* kinematical chain. But, the mechanism can be arranged to achieve only translational motions with certain conditions satisfied, i.e., in each kinematical chain the axis of the first revolute joint is parallel to that of the last one and the two intermediate joint axes are parallel to one another. There are three active mobile prismatic joints and six passive universal joints. The first leg *A* is typically contained within the Ox_0z_0 vertical plane, whereas the remaining legs B, C make the angles $\alpha_B = 120^0, \alpha_C = -120^0$ respectively, with the first leg (Fig. 2).

For the purpose of analysis, we assign a fixed Cartesian coordinate system $Ox_0y_0z_0(T_0)$ at the centred point *O* of the fixed base platform and a mobile frame $Gx_Gy_Gz_G$ on the mobile platform at its centre *G*. The angle ν between Ox_0 and Gx_G axes is defined as the *twist* angle of the robot.

The moving platform is initially located at a *central configuration*, where the platform is not translated with respect to the fixed base and the origin *O* of the fixed frame is located at an elevation $OG = h$ above the mass centre *G*.

To simplify the graphical image of the kinematical scheme of the mechanism, in what follows we will represent the intermediate reference systems by only two axes, so as is used in most of robotics papers [1], [2], [8]. It is noted that the relative rotation with angle $\varphi_{k,k-1}$ or the relative translation of the body T_k with the displacement $\lambda_{k,k-1}$ must always be pointed along the direction of the z_k axis.

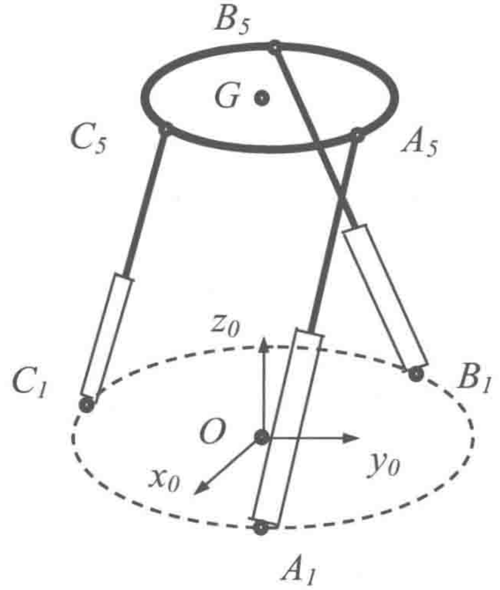


Fig. 1 Symmetric spatial 3-*UPU* parallel robot

The first active leg *A*, for example, consists of the cross of a fixed Hooke joint linked at the frame $A_1x_1^Ay_1^Az_1^A$, characterised by absolute angle of rotation φ_{10}^A, angular velocity $\omega_{10}^A=\dot{\varphi}_{10}^A$ and the angular acceleration $\varepsilon_{10}^A=\ddot{\varphi}_{10}^A$, connected at a moving cylinder $A_2x_2^Ay_2^Az_2^A$ of length l_2, which has a relative rotation around $A_2z_2^A$ axis with the angle φ_{21}^A, so that $\omega_{21}^A=\dot{\varphi}_{21}^A, \varepsilon_{21}^A=\ddot{\varphi}_{21}^A$. An actuated prismatic joint is as well as a piston of length l_3 linked to the $A_3x_3^Ay_3^Az_3^A$ frame, having a relative displacement λ_{32}^A, velocity $v_{32}^A=\dot{\lambda}_{32}^A$ and acceleration $\gamma_{32}^A=\ddot{\lambda}_{32}^A$. Finally, a second universal joint $A_4x_4^Ay_4^Az_4^A$ having the angular velocity $\omega_{43}^A=\dot{\varphi}_{43}^A$ and the angular acceleration $\varepsilon_{43}^A=\ddot{\varphi}_{43}^A$ is introduced at the edge of a moving platform, which can be schematised as a circle of radius r in a relative rotation around $A_5z_5^A$ axis with angular velocity $\omega_{54}^A=\dot{\varphi}_{54}^A$ and angular acceleration $\varepsilon_{54}^A=\ddot{\varphi}_{54}^A$.

At the central configuration, we also consider that the three sliders are initially starting from the same position $l_1=h/\sin\beta-l_2$ and that the angles of orientation of universal joints are given by

$$\alpha_A=0,\ \alpha_B=\frac{2\pi}{3},\ \alpha_C=-\frac{2\pi}{3},\ \nu=\frac{\pi}{6} \tag{1}$$

$$(l_0-r\cos\nu)\tan\delta=r\sin\nu,\ \ r\sin\nu\tan\beta=h\sin\delta,$$

where δ and β are two constant angles of rotation around the axes z_1^A and z_2^A, respectively.

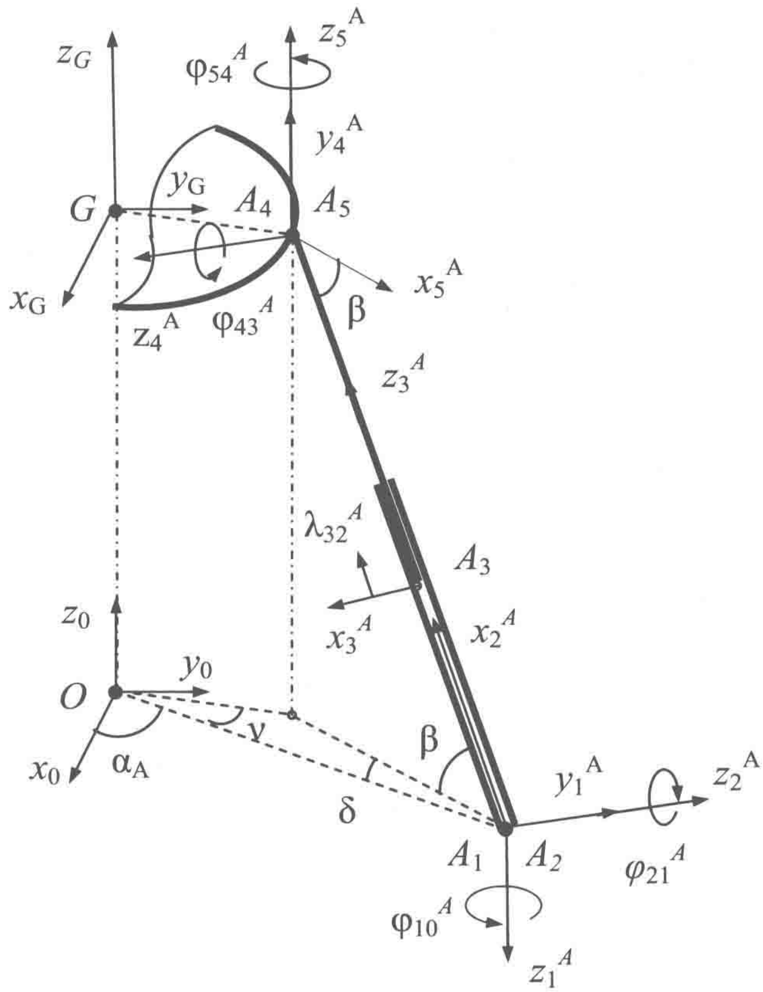


Fig. 2 Kinematical scheme of first leg A of parallel mechanism

Starting from the reference origin O and pursuing along three independent legs $OA_0A_1A_2A_3A_4$, $OB_0B_1B_2B_3B_4$, $OC_0C_1C_2C_3C_4$, we obtain following transformation matrices

$$p_{10} = p_{10}^{\varphi} a_{\delta} \theta_3 a_{\alpha}^{i},\; p_{21} = p_{21}^{\varphi} a_{\beta} \theta_1^{T},\; p_{32} = \theta_2,\; p_{43} = p_{43}^{\varphi} a_{\beta} \theta_2,\; p_{54} = p_{54}^{\varphi} \theta_1^{T} \tag{2}$$

$$p_{20} = p_{21} p_{10},\; p_{30} = p_{32} p_{20},\; p_{40} = p_{43} p_{30},\; p_{50} = p_{54} p_{40} \quad (p = a, b, c), \quad (i = A, B, C),$$

where we denote the matrices [12]:

$$a_{\alpha}^{i} = rot(z, \alpha_i),\; a_{\delta} = rot(z, \delta),\; a_{\beta} = rot(z, \beta)$$

$$\theta_1 = rot(x, \pi/2),\; \theta_2 = rot(y, \pi/2),\; \theta_3 = rot(y, \pi),\; p_{k,k-1}^{\varphi} = rot(z, \varphi_{k,k-1}^{i}). \tag{3}$$