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Structural Analysis of Spatial Mechanisms

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Abstract: The paper briefly presents how structural analysis is performed on spatial mechanisms, presenting a practical application in the mechatronics of parallel robots, especially in Steward platforms. Structural analysis always helps to better understand the phenomena and especially the way the mechanisms are made. At spatial mechanisms the problems are a little more complex than those raised by plane mechanisms. For this reason, the present paper tries to fill a gap in the field, especially as very few specialists in the theory of mechanisms of robots and machines still work today such structures on the basis of the theoretical knowledge, the modalities and working methods being approached being the most often based on approximate calculations, empirical formulas, or simply on experimental findings, woven with computerized theoretical modeling, but lacking in the essence of the underlying theory that is no longer so well-known. The structure and geometry of the mechanisms represent basically the basic elements that need to be studied primarily when we want to analyze such a mechanism already built and especially when we want to synthesize a new one.

Keywords: Mechanisms, Structure, Spatial Mechanisms Structure, Robots, Mechatronics, Automation, Parallel Robots, Spatial Mechanisms, Steward Platform, Structure and Geometry, Machines Structure

Introduction

The paper briefly presents how structural analysis is performed on spatial mechanisms, presenting a practical application in the mechatronics of parallel robots, especially in Steward platforms.

Structural analysis always helps to better understand the phenomena and especially the way the mechanisms are made.

At spatial mechanisms the problems are a little more complex than those raised by plane mechanisms. For this reason, the present paper tries to fill a gap in the field, especially as very few specialists in the theory of mechanisms of robots and machines still work today such structures on the basis of the theoretical knowledge, the modalities and working methods being approached being the most often based on approximate calculations, empirical formulas, or simply on experimental findings, woven with computerized theoretical modeling, but lacking in the essence of the underlying theory that is no longer so well-known.

The structure and geometry of the mechanisms represent basically the basic elements that need to be studied primarily when we want to analyze such a mechanism already built and especially when we want to synthesize a new one.

Spatial mechanisms are generally more complex than planar ones and therefore both their analysis as well as their optimal design is much more difficult to achieve. Spatial mechanisms are almost as old as planes, but their use has generally been rarer, making it much more difficult to design, build and use.

Engines of all kinds, as well as the various mechanical transmissions, that is, the most widespread mechanisms of all time, are built only by plane mechanisms, which has led to a thorough study of them, to the detriment of the spatial ones, much more difficult to study and still less useful so far.

After the robots appeared, however, things were radically changed, often spatial and often including spatial action mechanisms or elements, so that the necessity of grasping spatial problems into mechanisms became an undeniable objective reality.

Further, the structural analysis of the general, spatial, or plane + spatial mechanisms will be pursued.

The generalized structural formula of the mechanisms (Dobrovolschi) allows to determine the degree of mobility of the family f mechanisms, taking into account the number f of the common bonding conditions imposed on all the elements of the mechanism before being linked in a single or multi- of the same family).

The kinematic chain is a reunion of kinematic elements of different ranks linked by kinematic couplers of different classes. All elements of the kinematic chain are mobile.

For a kinematic chain to be used, it must first be fastened to one of the component parts.

The classification of the kinematic chains is based on three important criteria: The rank of the component elements, the shape of the chain and the way the elements are moved.

A. By the rank of the elemental elements of the chain, we have:

- Simple kinematics (where each component has at most two kinematic couplings, *j* being at most 2)
- Complex cinematic lines (at least one element of which has more than two kinematic couplings, or at least one top-level contour of at least 4, belonging to a higher tetrade or higher structural group)

B. According to the kinematic chain, we have:

- Kemematic open lanes (there are also elements with one kinematic couple, e.g., serial robots)
- Closed kinematic lanes (where all elements have at least two kinematic couplers, with the most common mechanisms, including parallel robots)

C. By the way we move elements, we have:

- Kinematic planar lanes (where all elements move in one plane, or in parallel planes)
- Kinematic spatial lanes (at least one of which has a movement in a different plan than the others)

The mechanisms are formed from one or more kinematic chains by fixing an element and the setting of the leading element (or the leading elements).

Space mechanisms are today used very often in the robotics and mechatronics industry, in the aerospace industry and in various specialized applications (Frăţilă *et al*., 2011; Pelecudi, 1967; Antonescu, 2000; Comănescu *et al*., 2010; Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Mirsayar *et al*., 2017; Cao *et al*., 2013; Dong *et al*., 2013; De Melo *et al*., 2012; Garcia *et al*., 2007; Garcia-Murillo *et al*., 2013; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al*., 2009; 2016a; 2016b; 2016c; 2016d; 2016e; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; Petrescu and Calautit, 2016a; 2016b; Reddy *et al*., 2012; Tabaković *et al*., 2013; Tang *et al*., 2013; Tong *et al*., 2013; Wang *et al*., 2013; Wen *et al*., 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; List the first flights, From Wikipedia; Chen and Patton, 1999; Fernandez *et al*., 2005; Fonod *et al*., 2015; Lu *et al*., 2015; 2016; Murray *et al*., 2010; Palumbo *et al*., 2012; Patre and Joshi, 2011; Sevil and Dogan, 2015; Sun and Joshi, 2009; Crickmore, 1997; Goodall, 2003; Graham, 2002; Jenkins, 2001; Landis and Dennis, 2005; Clément, Wikipedia; Cayley, Wikipedia; Coandă-1910, Wikipedia; Gunston, 2010; Laming, 2000; Norris, 2010; Goddard, 1916; Kaufman, 1959; Oberth, 1955; Cataldo, 2006; Gruener, 2006; Sherson *et al*., 2006; Williams, 1995; Venkataraman, 1992; Oppenheimer and Volkoff, 1939; Michell, 1784; Droste, 1915; Finkelstein, 1958; Gorder, 2015; Hewish, 1970).

Materials and Methods

The mechanisms are formed from one or more kinematic chains by fixing an element and the setting of the leading element (or the leading elements).

The f family of a suitable kinematic mechanism or kinetic chain is defined, the space in which elements before being linked by kinematic couplers have 6 degrees of freedom.

In a family space f formed mechanisms can have in their structure only kinematic class couplings $k \geq f+1$. For example, in a third family space, where $f = 3$ (which may be a plane or a space-spherical one), we can only have fourth and fifth class couplings.

Consequently, in the family space f, the isolated elements possess (6-*f*) degrees of freedom. By linking them through kinematic couples $\sum_{k=f+1}^{5} c_k$, the degree of freedom of the chain formed will be (I):

$$L_f = (6-f)\cdot e - \sum_{k=f+1}^{5}(k-f)\cdot c_k \tag{I}$$

Because a kinematic k-class coupling suppresses element (*k-f*) degrees of freedom. Relationship (I) is the structural formula of the single-contour kinematic chain *f*.

If one of the chain elements is attached, the degree of mobility of the family *f* mechanism (formula

Dobrovolschi, system II) is obtained, where m = the number of mobile elements:

$$\begin{cases} M_f = L_f - (6-f) \\ M_f = (6-f)\cdot(e-1) - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \end{cases} \quad \text{(II)}$$

There are six families of mechanisms, derived from the system (II), according to the system (III):

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ f = 0 M_0 = 6m - 5c_5 - 4c_4 - 3c_3 - 2c_2 - c_1 \\ f = 1 M_1 = 5m - 4c_5 - 3c_4 - 2c_3 - c_2 \\ f = 2 M_2 = 4m - 3c_5 - 2c_4 - c_3 \\ f = 3 M_3 = 3m - 2c_5 - c_4 \\ f = 4 M_4 = 2m - c_5 \\ f = 5 M_5 = m \end{cases} \quad \text{(III)}$$

The family of the mechanism can be determined using the table method, which is to list in a table all the independent movements of the elements with respect to a convenient coordinate axis system. The number of restrictions common to all elements indicates the family f of the mechanism. The formula for the obtained family (chosen from system III) is then applied and the mobility of the mechanism is obtained.

Note: The table method cannot be used in any situation to determine the family of a space mechanism.

In order to be used in as many cases as possible, it is sometimes useful to equate smaller upper class couplings with additional elements and fifth-grade inferior couplings. The fixed Cartesian space coordinate system must be judiciously chosen.

The spatial mechanisms of the f = 0 family are constituted by elements whose movements are not subject to any common restriction.

This category includes the spatial mechanisms whose elements can perform the most general movements (e.g., the steering mechanism of the road vehicles, the braking mechanism of the railway vehicles, the suspension mechanism, the motorbike, the automatic pilot steering mechanism, the modern parallel systems, etc.).

Such a family mechanism 0 is the spatial quadrilateral mechanism of Fig. 1, generally used as a steering mechanism on various road vehicles. To the right, you can see the table of elements moves towards the xOyz cartesian axis system chosen.

There is no common restriction, so the mechanism has the family 0 and the mobility is determined by the zero family formula (see relationship IV):

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ f = 0 \quad M_0 = 6m - 5c_5 - 4c_4 - 3c_3 - 2c_2 - c_1 \\ = 6\cdot 3 - 5\cdot 2 - 4\cdot 0 - 3\cdot 2 - 2\cdot 0 - 0 = 18 - 10 - 6 = 2 \end{cases} \quad \text{(IV)}$$

The degree of mobility of the mechanism resulted in two, but the kinematic mechanism is desmodrome with a single actuation, so its real mobility degree is 1.

The second mobility is the possibility of the space bar 2 to rotate randomly around its own longitudinal axis due to the permittivity of the two couplings Spherical third-class spheres at its ends.

Another family zero mechanism is represented in Fig. 2.

Figure 3 shows a RCCR space family mechanism 1.

The inlet and outlet axes of the cranks 1 and 3 are constructed with 5th-class rotary couplings, but the bell 2 is connected to the cranks by fourth-class cylindrical couplings.

There is a common restriction (none of the three movable elements can rotate around the x-axis).

The degree of mobility of the mechanism is obtained with the relation (V) related to the spatial mechanisms of the family 1:

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ f = 1 \quad M_1 = 5m - 4c_5 - 3c_4 - 2c_3 - c_2 \\ = 5\cdot 3 - 4\cdot 2 - 3\cdot 2 - 2\cdot 0 - 0 = 15 - 8 - 6 = 1 \end{cases} \quad \text{(V)}$$

Figure 4 is a family 2 mechanism.

The degree of mobility of the mechanism with screw 1 and rod 2, family 2, is obtained with the corresponding formula (VI):

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ f = 2 \quad M_2 = 4m - 3c_5 - 2c_4 - c_3 \\ = 4\cdot 4 - 3\cdot 5 - 2\cdot 0 - 0 = 16 - 15 = 1 \end{cases} \quad \text{(VI)}$$

The family mechanisms f = 3 consist of elements whose movements have three common restrictions. There are three main categories in this family:

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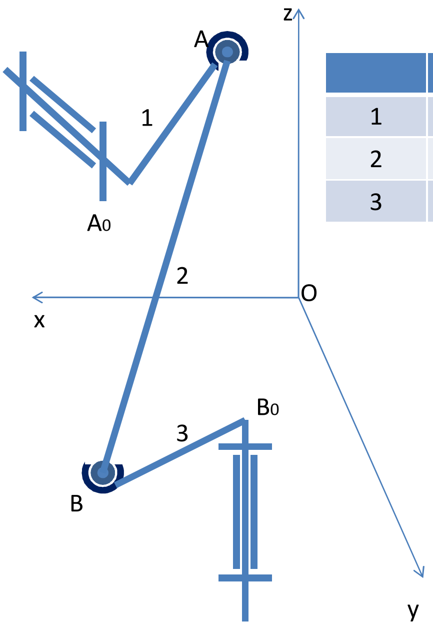
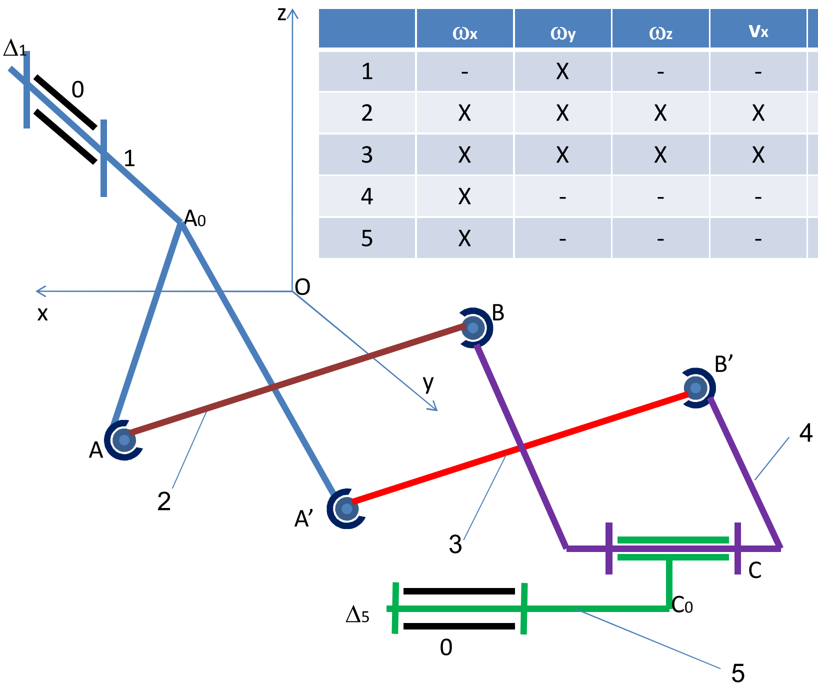
A. Spherical mechanisms (the elements of these mechanisms are forbidden by all three translations, the elements are located on a sphere, they have the possibility to perform only the three rotations). Example (fourth-class couplings). Refer to the universal or universal coupling in Fig. 5.



	ω_x	ω_y	ω_z	v_x	v_y	v_z
1	-	X	-	-	-	-
2	X	X	X	X	X	X
3	-	-	X	-	-	-

Fig. 1: Spatial quadrilateral mechanism used as steering mechanism on road vehicles



	ω_x	ω_y	ω_z	v_x	v_y	v_z
1	-	X	-	-	-	-
2	X	X	X	X	X	X
3	X	X	X	X	X	X
4	X	-	-	-	X	X
5	X	-	-	-	-	-

Fig. 2: Space mechanism used as a mobile coupling to electric locomotives

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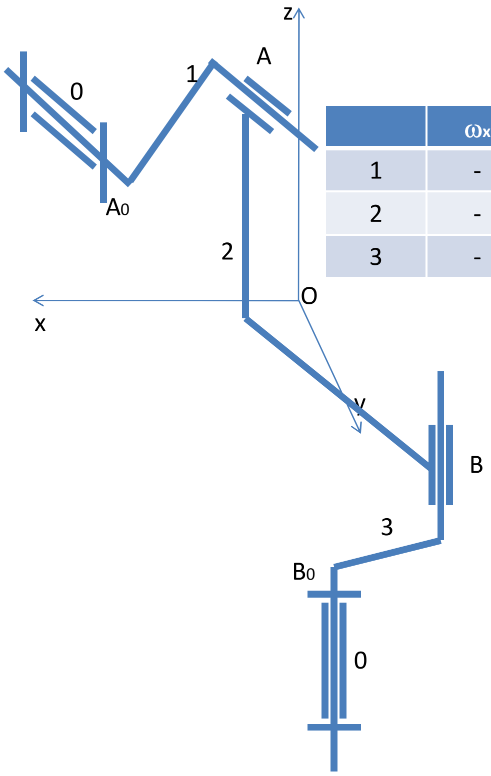
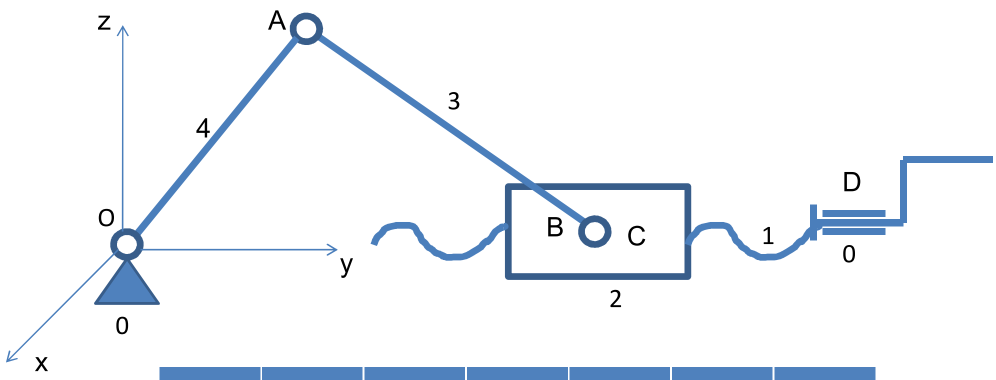


	ω_x	ω_y	ω_z	v_x	v_y	v_z
1	-	X	-	-	-	-
2	-	X	X	X	X	X
3	-	-	X	-	-	-

Fig. 3: Space RCCR Family 1 Mechanism



	ω_x	ω_y	ω_z	v_x	v_y	v_z
1	-	X	-	-	-	-
2	-	-	-	-	X	-
3	X	-	-	-	X	X
4	X	-	-	-	-	-

Fig. 4: Space Family 2 Mechanism

Fig. 5: The Cardan Cross (Universal Fourth Coupling) is a spherical spatial mechanism of family 3

Fig. 6: Double cardan articulation is a spherical spatial mechanism of the family 1

The mobility of such a mechanism (m = 2, C5 = 2, C4 = 1) is determined with the related relationship (VII):

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k f = 3 \\ M_3 = 3m - 2c_5 - c_4 = 3\cdot 2 - 2\cdot 2 - 1 = 6 - 4 - 1 = 1 \end{cases} \quad \text{(VII)}$$

It should be noted here that the mechanism with two cardanic crossings and a cardan shaft between them (as used in vehicles, Fig. 6) turns into a family mechanism 1 (f = 1) because if we take a system spatial Cartesian axes having a common axis with the longitudinal axis of the shaft, we can see that the spindle has the three space rotation imposed by the cardan couplings at its ends plus two spatial translatations along the radial directions but does not translate along its own longitudinal axis the only common restriction to the entire mechanism consisting of three mobile elements m = 3, two C5 couplings and two C4 couplings). The mobility of the double joint is obtained with the VIII:

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \\ f = 1 M_1 = 5m - 4c_5 - 3c_4 - 2c_3 - c_2 \\ = 5\cdot 3 - 4\cdot 2 - 3\cdot 2 - 2\cdot 0 - 0 = 15 - 8 - 6 = 1 \end{cases} \quad \text{(VIII)}$$

B. Flat devices (in which the rotation, translation, nuts and C4 upper couplings are formed).

The planar mechanisms are the most common in the technique, being practically the most used mechanisms in the entire history of mankind. Today, however, spatial mechanisms are being diversified due to advanced technologies and the emergence of parallel mobile structures.

C. Spatial space mechanisms (whose elements can only have translational movements in space.

The mechanisms of the f = 4 family are made up of elements whose movements have four common restrictions. For example, the flat wedge mechanisms (having three translational couplings, Fig. 7a), or the press-screw type mechanisms (a rotation coupler, one translation and one screw nut, Fig. 7b), where one meet two mobile elements and three fifth-class couplings. Mobility is given by relation (IX):

$$\begin{cases} M_f = (6-f)\cdot m - \sum_{k=f+1}^{5} (k-f)\cdot c_k \quad f=4 \\ M_4 = 2m - c_5 = 2\cdot 2 - 3 = 4 - 3 = 1 \end{cases} \tag{IX}$$

Clarifications: The family mechanism f = 5 is not alone, it falls into all the other families.

The Dobrovolschi formula also applies to polyclonal mechanisms, provided that all the independent contours of the mechanism have the same family. Otherwise, the modified Dobrovolschi formula (relation X) is used, where instead of f (the apparent family) and k takes values from 1 to 5 (not limited to f+1 to 5):

$$M_f = (6-f_a)\cdot m - \sum_{k=1}^{5}(k-f_a)\cdot c_k \tag{X}$$

The apparent family is determined as an arithmetic mean of the families of all independent contours (XIth relationship):

$$f_a = \frac{1}{N}\cdot\sum_{i=1}^{N} f_i \tag{XI}$$

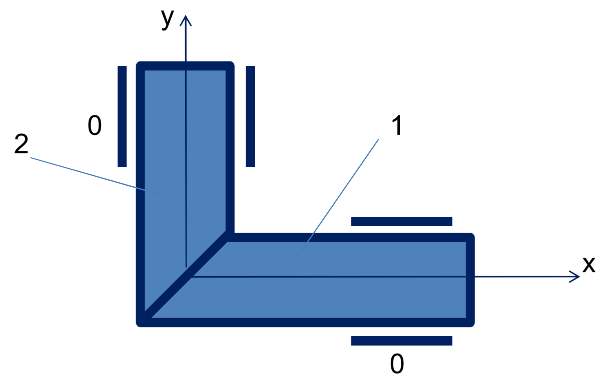
Independent contours are identified directly on the mechanism. The number of independent contours can also be checked with relation (XII):

$$N = \sum_{k=1}^{5} c_k - m \tag{XII}$$

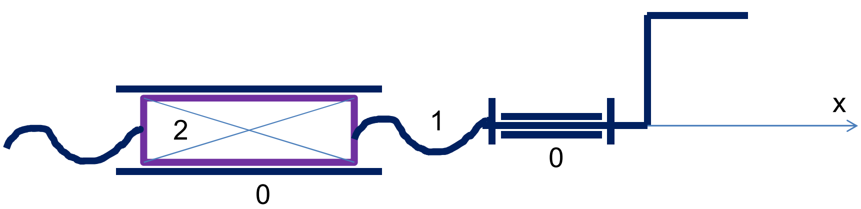
As an example of a complex mechanism, the mechanism of Fig. 8, which has 8 fifth-class couplings, 6 movable elements and two independent contours, 012340 and 04560, is taken as an example of a complex mechanism. For the first independent contour, the family is f = 2 and for the second family is f = 3.

With relation XI we obtain f_a = 2,5. The mobility of the mechanism is determined by the relation (XIII) that introduces the numerical data of the problem in relation (X):

$$M_f = (6-f_a)\cdot m - \sum_{k=1}^{5}(k-f_a)\cdot c_k \\ = (6-2.5)\cdot 6 - (5-2.5)\cdot 8 = 3.5\cdot 6 - 2.5\cdot 8 = 21 - 20 = 1 \tag{XIII}$$



a)



b)

Fig. 7: Family 4 mechanisms

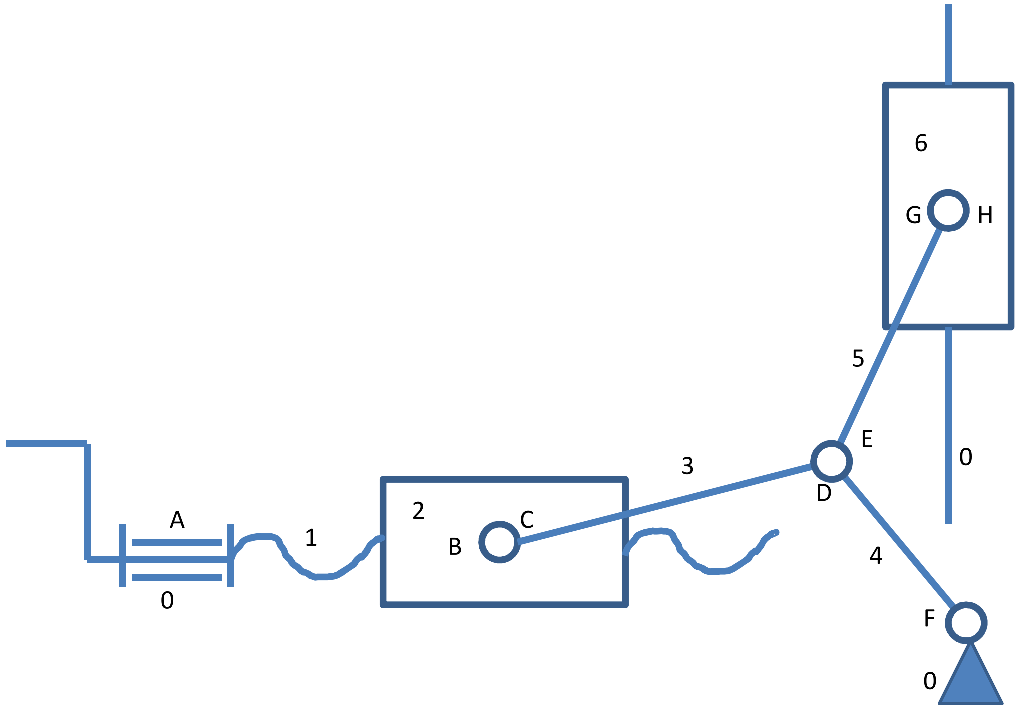


Fig. 8: Complex mechanism with two independent contours

Results and Discussion (Structure of Parallel Mobile Mechanical Systems)

Figure 9 shows the kinematic scheme of a parallel mobile mechanical system having all 12 kinematic couplings (linking the six motorized legs of the two platforms, fixed and movable) of spherical joints (spherical spherical couplings allowing all rotations possible and do not allow any translation to occur), practically third-class couplings (C3). The kinematic motor couplers (six in number) can be built in two variants: C5 or C4.

Ball spheres in sphere (spherical joints) allow rotations in space on all three axes and stop all translations. They are more technologically difficult, more expensive and generally have shorter lives and their wear is quite fast (even if the ball sphere contact surface is large). They have the great advantage of a reduced gauge (mass and low volume), (Fig. 10). Their life can be prolonged by optimal design, by thorough machining, by proper lubrication, etc. Spherical joints are used in the machinery industry, especially in the automotive industry. They are encountered in wheel attachment systems (swivel pivots), steering system joints, rear-view mirrors, some gearbox changers, etc.

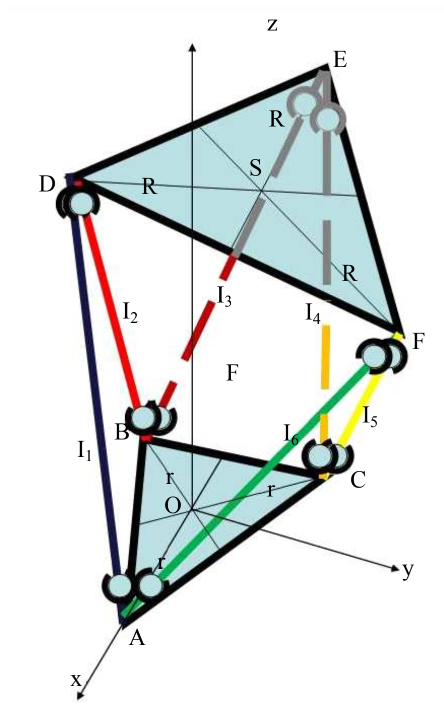


Fig. 9: The joints between the legs and the platforms must normally be all spherical kinematic spheres, that is, third class (C3) kinematic couplers

Fig. 10: Spherical joints have multiple uses

For a system parallel to 12 spherical articulations (C3) and 6 fifth-order (C5) engine couples (C5), the mobility of the system (spatial mechanism) is calculated by the general formula (1), (for a family spatial mechanism 0):

$$\begin{aligned} M_0 &= 6\cdot m - 5\cdot C_5 - 4\cdot C_4 - 3\cdot C_3 - 2\cdot C_2 - 1\cdot C_1 \\ &= 6\cdot m - 5\cdot C_5 - 3\cdot C_3 = 6\cdot 13 - 5\cdot 6 - 3\cdot 12 \\ &= 78 - 30 - 36 = 12 \end{aligned} \quad (1)$$

where, *m* represents the number of movable elements of the mechanism (system), in this case m is equal to 13, since the six movable legs are each formed by two elements (i.e., 6*2 = 12) and one of the platforms is also mobile (representing the thirteenth mobile element of the system).

Out of the 12 mobility degrees of the system, only 6 are active (representing the linear movements of linear motors). The other six degrees of mobility are passive (does not indicate the need to use additional actuators to achieve them). They are basically materialized by six additional six-foot rotation movements, each leg consisting of two kinematic elements, considered to be a solid, freely rotatable between its two spherical joints (through which it is connected to the two platforms, the fixed one from the base and the upper movable), (Fig. 11).

Although in general this passive rotation is random (cinematic is not necessary), however, it helps to improve the dynamic movement (movement) of the mechanism (system).

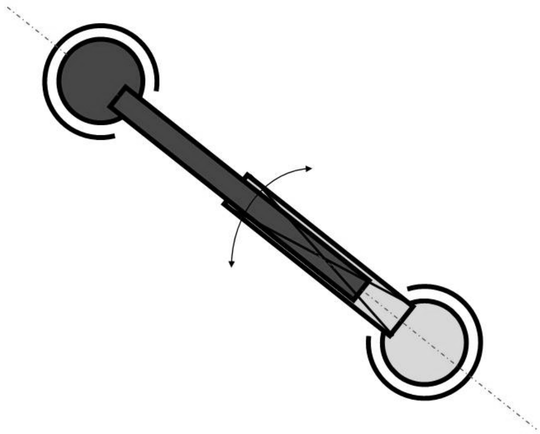


Fig. 11: Passive rotation of the motor foot between the two spherical joints (C3). The rotation between the translation elements is not allowed when the motor coupling is a fifth-order translation (C5)

In fact, cylindrical (C4) engine couplings are used in place of the translational drive couplings (C5) which, besides the translational movement, also allow a relative rotation movement between the two rods of the motor coupler. Linear actuators are built in such a way that each allows a relative rotation movement between the two active bars. The motor movement is the linear motion, but a relative rotation motion within the motorcycle is also allowed.

In this situation, the six fifth-class couplings (C5) disappear and they are completely replaced by Class IV cylindrical mobile joints (C4) (Fig. 12). The formula of degree of mobility takes the look (2):

$$\begin{aligned} M_0 &= 6\cdot m - 5\cdot C_5 - 4\cdot C_4 - 3\cdot C_3 - 2\cdot C_2 - 1\cdot C_1 \\ &= 6\cdot m - 4\cdot C_4 - 3\cdot C_3 = 6\cdot 13 - 4\cdot 6 - 3\cdot 12 \\ &= 78 - 24 - 36 = 18 \end{aligned} \quad (2)$$

The mechanism increases mobility, but only six of these mobilities are active (they refer to the linear movements imposed by the six actuators). In this case we have 12 passive rotation movements.

Both variants are not only functional but also have a better dynamic.

They were used by Stewart at first. He then proposed a more rigid (more dynamic) and more economical system, in which six of the spherical joints (C3) were replaced by six universal joints (cardanic cross, etc.), i.e., with couplings class IV.

So, out of the 12 C3 spherical couplings, half (six C3 couplings) are left to use, while six others will be of the fourth class (universal joints) and together with the Cylinder Engines (C4) they will achieve at the Stewart platform 12 C4 couplings. Mobility will be given by formula (3):

$$\begin{aligned} M_0 &= 6\cdot m - 5\cdot C_5 - 4\cdot C_4 - 3\cdot C_3 - 2\cdot C_2 - 1\cdot C_1 \\ &= 6\cdot m - 4\cdot C_4 - 3\cdot C_3 = 6\cdot 13 \\ &-4\cdot 12 - 3\cdot 6 = 78 - 48 - 18 = 12 \end{aligned} \quad (3)$$

He immediately imposed himself and although it was thought that by replacing all universal spherical joints, the system would no longer work, yet somebody tried and saw that it was going and so and so it remained. The vast majority of Stewart's parallel platforms today have 12 universal joints and 6 cylindrical engine couplings, all of them being Class 4 kinematic couplings.

The C3 joints and the C5 sprockets disappear and only universal joints and cylindrical motors, all of the C4 kinematic class, remain (Fig. 13).

The universal joints used can be constructively of several ways (Fig. 14).

The formula for calculating mobility is now written in much simplified form (4):

$$\begin{aligned} M_0 &= 6\cdot m - 5\cdot C_5 - 4\cdot C_4 - 3\cdot C_3 - 2\cdot C_2 - 1\cdot C_1 \\ &= 6\cdot m - 4\cdot C_4 = 6\cdot 13 - 4\cdot 18 = 78 - 72 = 6 \end{aligned} \quad (4)$$

Although it seems the most rigid (dynamic) mechanism with only six degrees of mobility, all assets, representing the six linear motions of the six actuators, this system without additional, passive, rotating mobilities has succeeded in imposing a more judicious (both economically and financially but also technologically, being easier to achieve, cheaper and more reliable, Fig. 13 and 15).

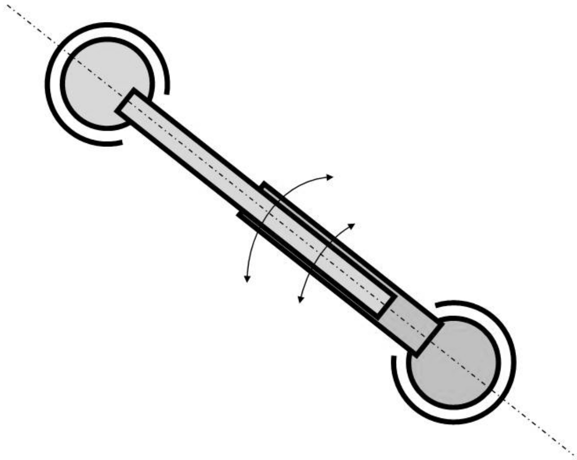


Fig. 12: Besides the passive rotation of the motor foot between the two spherical joints (C3), there is also a rotation between the two translation elements. A four-cylinder, 4th grade (C4) kinematic coupling is used

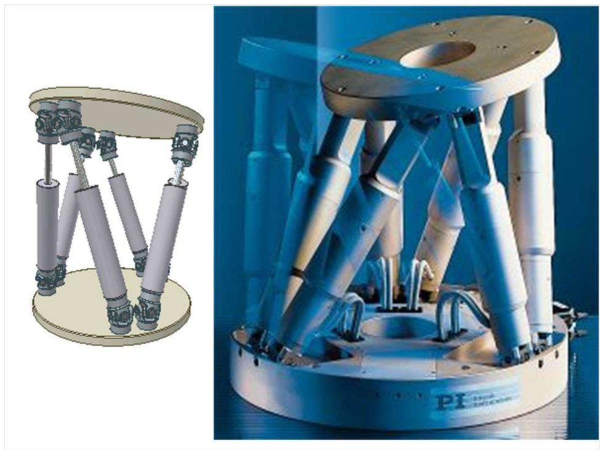


Fig. 13: Modern Stewart platforms with 12 universal joints

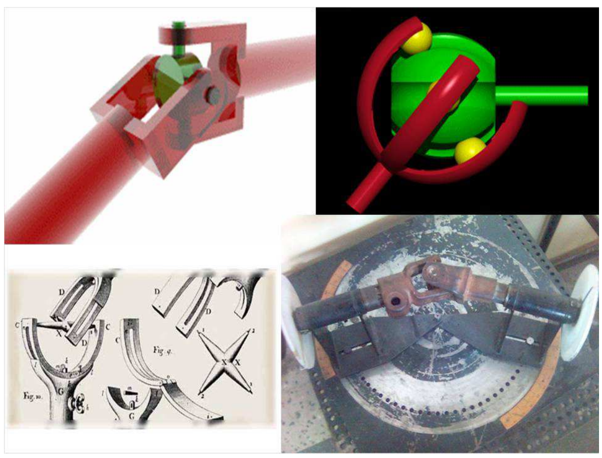


Fig. 14: Universal joints (their constructive diversity is great)

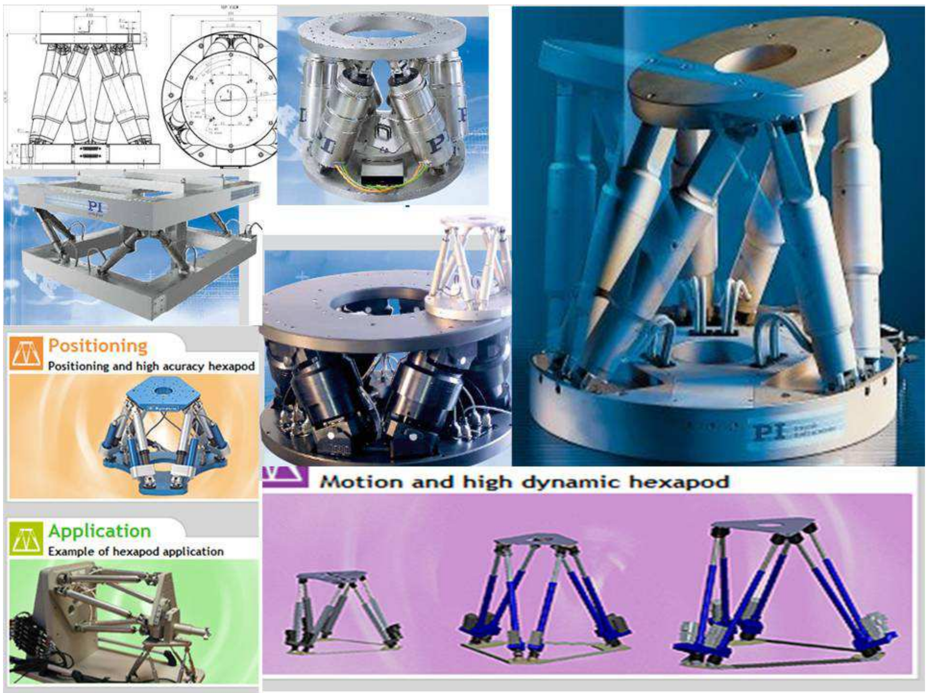


Fig. 15: Modern Stewart platforms with universal joints

Fig. 16: System parallel to nine hydraulic linear legs

Linear motors (actuators) are often hydraulic. They can also be electric, pneumatic, etc., but the most used are the hydraulic ones.

Their advantages (hydraulic actuators in particular, but also parallel systems in general) are primarily represented by high operating speeds (like actuator systems from specialized tractors), high speeds while keeping a good dynamics. Balancing them is simpler (for hydraulic systems, which act by default not only as engines but also as hydraulic shock absorbers, simultaneously). Parallel systems (generally) are faster, more dynamic, better balanced, quieter and especially "more rigid and more precise" compared to serial structures.

Where high rigidity and high accuracy are required, it will be considered (from the outset) the use of a parallel mobile mechanical system (for medical, brain, or spinal cord operations, for example in toxic, chemical, nuclear, heavy industry, etc.).

Although it seems exaggerated, in some of the aforementioned environments (on spinal surgery), devices based on super rigid parallel platforms were introduced at the request of specialists by supplementing the six engine legs with three more, thus resulting in nine legs (Fig. 16).

We now have nine feet, each of which contains two moving kinematic elements and three C4 couplings.

The number of mobile elements, m, now stands at 9*2+1 = 19. The kinematic couples are only of the fourth class, C4 = 9*3 = 27. The formula of the mechanism (system) mobility is given by the relationship (5):

$$\begin{aligned} M_0 &= 6\cdot m - 5\cdot C_5 - 4\cdot C_4 - 3\cdot C_3 - 2\cdot C_2 - 1\cdot C_1 \\ &= 6\cdot m - 4\cdot C_4 = 6\cdot 19 - 4\cdot 27 = 114 - 108 = 6 \end{aligned} \tag{5}$$

The system with only six degrees of mobility (all assets) will work the same as the one presented in the present work with the six lateral actuators and the three additional legs will not be additional hydraulic motors, but only additional hydraulic shock absorbers; they will be virtually pulled up permanently by the upper movable platform and will always resist the movement (they will make a brake and a further damping). The rigidity of the system will increase significantly.

Although it looks much more complex (at first glance), this system is the same as the classic one (with six lateral actuators) and the calculations are the same as the classic Stewart system presented.

The three additional legs achieve only better stability, support, braking and especially increased rigidity of the entire system.

If nine effective actuators are to be implemented, then the structure of the mechanism to achieve some additional mobility (at least three) must be rethought. For every universal joint transformed into a spherical one, a degree of additional mobility is obtained. To have the mechanism 9 instead of 6, three universal joints must be replaced by three spherical kinematic spheres. The most logical would be to replace the three upper legs of the extra legs. In this case, the mobility formula takes the form (6):

$$\begin{aligned} M_0 &= 6 \cdot m - 5 \cdot C_5 - 4 \cdot C_4 - 3 \cdot C_3 - 2 \cdot C_2 - 1 \cdot C_1 \\ &= 6 \cdot m - 4 \cdot C_4 - 3 \cdot C_3 = 6 \cdot 19 - 4 \cdot 24 - 3 \cdot 3 \\ &= 114 - 96 - 9 = 9 \end{aligned} \tag{6}$$

Fig. 17: System parallel to six hydraulic linear load actuators in motion

In this situation, the theory also changes.

Even the classical parallel systems presented have a very high stiffness and very good precision and can maintain their balance during fast moving loads with a high loading load (see photo in Fig. 17).

The load is very high, the travel speeds are high, the big and sudden inclines are not missing either. As can be seen in Fig. 17, the load is not anchored, but it is laid freely on the upper (upper) platform.

Conclusion

The paper briefly presents how structural analysis is performed on spatial mechanisms, presenting a practical application in the mechatronics of parallel robots, especially in Steward platforms.

Structural analysis always helps to better understand the phenomena and especially the way the mechanisms are made.

At spatial mechanisms the problems are a little more complex than those raised by plane mechanisms.

For this reason, the present paper tries to fill a gap in the field, especially as very few specialists in the theory of mechanisms of robots and machines still work today such structures on the basis of the theoretical knowledge, the modalities and working methods being approached being the most often based on approximate calculations, empirical formulas, or simply on experimental findings, woven with computerized theoretical modeling, but lacking in the essence of the underlying theory that is no longer so well-known.

The structure and geometry of the mechanisms represent basically the basic elements that need to be studied primarily when we want to analyze such a mechanism already built and especially when we want to synthesize a new one.

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Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

References

Antonescu, P., 2000. Mechanisms and Handlers, Printech Publishing House. Bucharest.

Antonescu, P. and F. Petrescu, 1985. Analytical method of synthesis of cam mechanism and flat stick. Proceedings of the 4th International Symposium on Mechanism Theory and Practice, (TPM’ 85), Bucharest.

Antonescu, P. and F. Petrescu, 1989. Contributions to cinetoelastodynamic analysis of distribution mechanisms. Bucharest.

Antonescu, P., M. Oprean and F. Petrescu, 1985a. Contributions to the synthesis of oscillating cam mechanism and oscillating flat stick. Proceedings of the 4th International Symposium on Theory and Practice of Mechanisms, (TPM’ 85), Bucharest.

Antonescu, P., M. Oprean and F. Petrescu, 1985b. At the projection of the oscillante cams, there are mechanisms and distribution variables. Proceedings of the V-Conference for Engines, Automobiles, Tractors and Agricultural Machines, I-Engines and Automobiles, (AMA’ 85), Brasov.

Antonescu, P., M. Oprean and F. Petrescu, 1986. Projection of the profile of the rotating camshaft acting on the oscillating plate with disengagement. Proceedings of the 3rd National Computer Assisted Designing Symposium in Mechanisms and Machine Bodies, (MOM’ 86), Brasov.

Antonescu, P., M. Oprean and F. Petrescu, 1987. Dynamic analysis of the cam distribution mechanisms. Proceedings of the 7th National Symposium of Industrial Robots and Spatial Mechanisms, (IMS’ 87), Bucharest.

Antonescu, P., M. Oprean and F. Petrescu, 1988. Analytical synthesis of Kurz profile, rotating flat cam. Machine Build. Rev. Bucharest.

Antonescu, P., F. Petrescu and O. Antonescu, 1994. Contributions to the synthesis of the rotating cam mechanism and the tip of the balancing tip. Brasov.

Antonescu, P., F. Petrescu and D. Antonescu, 1997. Geometrical synthesis of the rotary cam and balance tappet mechanism. Bucharest.

Antonescu, P., F. Petrescu and O. Antonescu, 2000a. Contributions to the synthesis of the rotary disc-cam profile. Proceedings of the 8th International Conference on Theory of Machines and Mechanisms, (TMM’ 00), Liberec, Czech Republic, pp: 51-56.

Antonescu, P., F. Petrescu and O. Antonescu, 2000b. Synthesis of the rotary cam profile with balance follower. Proceedings of the 8th Symposium on Mechanisms and Mechanical Transmissions, (MMT’ 000), Timişoara, pp: 39-44.

Antonescu, P., F. Petrescu and O. Antonescu, 2001. Contributions to the synthesis of mechanisms with rotary disc-cam. Proceedings of the 8th IFToMM International Symposium on Theory of Machines and Mechanisms, (TMM’ 01), Bucharest, ROMANIA, pp: 31-36.

Aversa, R., R.V. Petrescu, A. Apicella and F.I.T. Petrescu, 2017a. Nano-diamond hybrid materials for structural biomedical application. Am. J. Biochem. Biotechnol., 13: 34-41. DOI: 10.3844/ajbbsp.2017.34.41

Aversa, R., R.V. Petrescu, B. Akash, R.B. Bucinell and J.M. Corchado *et al*., 2017b. Kinematics and forces to a new model forging manipulator. Am. J. Applied Sci., 14: 60-80. DOI: 10.3844/ajassp.2017.60.80

Aversa, R., R.V. Petrescu, A. Apicella, F.I.T. Petrescu and J.K. Calautit *et al*., 2017c. Something about the V engines design. Am. J. Applied Sci., 14: 34-52. DOI: 10.3844/ajassp.2017.34.52

Aversa, R., D. Parcesepe, R.V. Petrescu, F. Berto and G. Chen *et al*., 2017d. Processability of bulk metallic glasses. Am. J. Applied Sci., 14: 294-301. DOI: 10.3844/ajassp.2017.294.301

Aversa, R., R.V. Petrescu, A. Apicella and F.I.T. Petrescu, 2017e. Modern transportation and photovoltaic energy for urban ecotourism. Transylvanian Rev. Administrative Sci., 13: 5-20. DOI: 10.24193/tras.SI2017.1

Aversa, R., F.I.T. Petrescu, R.V. Petrescu and A. Apicella, 2016a. Biomimetic FEA bone modeling for customized hybrid biological prostheses development. Am. J. Applied Sci., 13: 1060-1067. DOI: 10.3844/ajassp.2016.1060.1067

Aversa, R., D. Parcesepe, R.V. Petrescu, G. Chen and F.I.T. Petrescu *et al*., 2016b. Glassy amorphous metal injection molded induced morphological defects. Am. J. Applied Sci., 13: 1476-1482. DOI: 10.3844/ajassp.2016.1476.1482

Aversa, R., R.V. Petrescu, F.I.T. Petrescu and A. Apicella, 2016c. Smart-factory: Optimization and process control of composite centrifuged pipes. Am. J. Applied Sci., 13: 1330-1341. DOI: 10.3844/ajassp.2016.1330.1341

Aversa, R., F. Tamburrino, R.V. Petrescu, F.I.T. Petrescu and M. Artur *et al*., 2016d. Biomechanically inspired shape memory effect machines driven by muscle like acting NiTi alloys. Am. J. Applied Sci., 13: 1264-1271. DOI: 10.3844/ajassp.2016.1264.1271

Bickford, J.H., 1972. Geneva Mechanisms. Mechanisms for Intermittent Motion (PDF). 1st Edn., Industrial Press Inc., New York, ISBN-10: 0-8311-1091-0, pp: 128.

Cao, W., H. Ding, Z. Bin and C. Ziming, 2013. New structural representation and digital-analysis platform for symmetrical parallel mechanisms. Int. J. Adv. Robot. Sys. DOI: 10.5772/56380

Cataldo, R., 2006. Overview of planetary power system options for education. ITEA Human Exploration Project Authors, Glenn Research Center, Brooke Park, OH.

Cayley George, From Wikipedia. The free encyclopedia.

Chen, J. and R.J. Patton, 1999. Robust Model-Based Fault Diagnosis for Dynamic Systems. 1st Edn., Kluwer Academic Publisher, Boston.

Clément, A., From Wikipedia. The free encyclopedia.

Coandă-1910, From Wikipedia. The free encyclopedia.

Comănescu, A., D. Comănescu, I. Dugăeşescu and A. Boureci, 2010. The Basics of Modeling Mechanisms. 1st Edn., Politehnica Press Publishing House, Bucharest, ISBN-10: 978-606-515-115-4, pp: 274.

Crickmore, P.F., 1997. Lockheed's blackbirds-A-12, YF-12 and SR-71A. Wings Fame, 8: 30-93.

Dong, H., N. Giakoumidis, N. Figueroa and N. Mavridis, 2013. Approaching behaviour monitor and vibration indication in developing a General Moving Object Alarm System (GMOAS). Int. J. Adv. Robot. Sys. DOI: 10.5772/56586

Droste, J., 1915. On the field of a single centre in Einstein's theory of gravitation. Koninklijke Nederlandsche Akademie van Wetenschappen Proc., 17: 998-1011.

De Melo, L.F., R.A., S.F. Rosário and J.M., Rosário, 2012. Mobile robot navigation modelling, control and applications. Int. Rev. Modell. Simulations, 5: 1059-1068.

Fernandez, V., F. Luis, L.F. Penin, J. Araujo and A. Caramagno, 2005. Modeling and FDI specification of a RLV Re-entry for robust estimation of sensor and actuator faults. Proceedings of the AIAA Guidance, Navigation and Control Conference and Exhibit, Aug. 15-18, San Francisco. DOI: 10.2514/6.2005-6254

Finkelstein, D., 1958. Past-future asymmetry of the gravitational field of a point particle. Physical Rev., 110: 965-967.

Fonod, R., D. Henry, C. Charbonnel and E. Bornschlegl, 2015. Position and attitude model-based thruster fault diagnosis: A comparison study. J. Guidance Control Dynam., 38: 1012-1026. DOI: 10.2514/1.G000309

Frăţilă, G., M. Frăţilă and S. Samoilă, 2011. Automobiles, Construction, Exploitation, Reparation. 10th Edn., EDP, Bucharest, ISBN-10: 978-973-30-2857-4.

Garcia, E., M.A. Jimenez, P.G. De Santos and M. Armada, 2007. The evolution of robotics research. IEEE Robot. Autom. Magaz., 14: 90-103. DOI: 10.1109/MRA.2007.339608

Garcia-Murillo, M., J. Gallardo-Alvarado and E. Castillo-Castaneda, 2013. Finding the generalized forces of a series-parallel manipulator. IJARS. DOI: 10.5772/53824

Goddard, 1916. Rocket apparatus patent December 15, 1916, Smithsonian Institution Archives.

Goodall, J., 2003. Lockheed's SR-71 "Blackbird" Family. Hinckley, UK: Aerofax/Midland Publishing, 2003. (ISBN 1-85780-138-5).

Gorder, P.F., 2015. What's on the surface of a black hole? Not a "firewall"—and the nature of the universe depends on it, a physicist explains.

Graham, R.H., 2002. SR-71 Blackbird: Stories, Tales and Legends. 1st Edn., Zenith Imprint, North Branch, Minnesota, ISBN-10: 1610607503.

Gruener, J.E., 2006. Lunar exploration (Presentation to ITEA Human Exploration Project Authors, November 2006, at Johnson Space Center). Houston, TX.

Gunston, B., 2010. Airbus: The Complete Story. 1st Edn., Haynes Publishing UK, Sparkford, ISBN-10: 1844255859, pp: 288.

He, B., Z. Wang, Q. Li, H. Xie and R. Shen, 2013. An analytic method for the kinematics and dynamics of a multiple-backbone continuum robot. IJARS. DOI: 10.5772/54051

Hewish, A., 1970. Pulsars. Ann. Rev. Astronomy Astrophys., 8: 265-296.

Jenkins, D.R., 2001. Lockheed Secret Projects: Inside the Skunk Works. 1st Edn., Zenith Imprint, St. Paul, Minnesota: MBI Publishing Company, ISBN-10: 1610607287.

Kaufman, H.R., 1959. Installations at NASA Glenn.

Laming, T., 2000. Airbus A320. 1st Edn., Zenith Press.

Landis, T.R. and D.R. Jenkins, 2005. Lockheed Blackbirds. 1st Edn., Specialty Press, North Branch, ISBN-10: 1580070868, pp: 104.

Lee, B.J., 2013. Geometrical derivation of differential kinematics to calibrate model parameters of flexible manipulator. Int. J. Adv. Robot. Syst. DOI: 10.5772/55592

Lin, W., B. Li, X. Yang and D. Zhang, 2013. Modelling and control of inverse dynamics for a 5-DOF parallel kinematic polishing machine. Int. J. Adv. Robot. Sys. DOI: 10.5772/54966

List the first flights, From Wikipedia, free encyclopedia.

Liu, H., W. Zhou, X. Lai and S. Zhu, 2013. An efficient inverse kinematic algorithm for a PUMA560-structured robot manipulator. IJARS. DOI: 10.5772/56403

Lu, P., L. Van Eykeren, E.J. Van Kampen and Q.P. Chu, 2015. Selective-reinitialization multiple-model adaptive estimation for fault detection and diagnosis. J. Guidance Control Dynam., 38: 1409-1424. DOI: 10.2514/1.G000587

Lu, P., L. Van Eykeren, E. van Kampen, C. C. de Visser and Q.P. Chu, 2016. Adaptive three-step kalman filter for air data sensor fault detection and diagnosis. J. Guidance Control Dynam., 39: 590-604. DOI: 10.2514/1.G001313

Michell, J., 1784. On the means of discovering the distance, magnitude and c. of the fixed stars, in consequence of the diminution of the velocity of their light, in case such a diminution should be found to take place in any of them and such other data should be procured from observations, as would be farther necessary for that purpose. Philosophical Trans. Royal Society, 74: 35-57. DOI: 10.1098/rstl.1784.0008

Mirsayar, M.M., V.A. Joneidi, R.V. Petrescu, F.I.T. Petrescu and F. Berto, 2017. Extended MTSN criterion for fracture analysis of soda lime glass. Eng. Fracture Mechan., 178: 50-59. DOI: 10.1016/j.engfracmech.2017.04.018

Murray, K., A. Marcos and L.F. Penin, 2010. Development and testing of a GNC-FDI filter for a reusable launch vehicle during ascent. Proceedings of the AIAA Guidance, Navigation and Control Conference, Aug. 2-5, Toronto, Ontario Canada. DOI: 10.2514/6.2010-8195

Norris, G., 2010. Airbus A380: Superjumbo of the 21st Century. 1st Edn., Zenith Press.

Oberth, H., 1955. They come from outer space. Flying Saucer Rev., 1: 12-14.

Oppenheimer, J.R. and G.M. Volkoff, 1939. On massive neutron cores. Physical Rev., 55: 374-381.

Padula, F. and V. Perdereau, 2013. An on-line path planner for industrial manipulators. Int. J. Adv. Robot. Syst. DOI: 10.5772/55063

Palumbo, R., G. Morani, M. De Stefano Fumo, C. Richiello and M. Di Donato *et al*., 2012. Concept study of an atmospheric reentry using a winged unmanned space vehicle. Proceedings of the 18th AIAA/3AF International Space Planes and Hypersonic Systems and Technologies Conference, Sept. 24-28, Tours, France. DOI: 10.2514/6.2012-5857

Patre, P. and S.M. Joshi, 2011. Accommodating sensor bias in MRAC for state tracking. Proceedings of the AIAA Guidance, Navigation and Control Conference, Aug. 8-11, American Inst. of Aeronautics and Astronautics, USA. DOI: 10.2514/6.2011-6605

Pelecudi, C., 1967. The Basics of mechanism analysis. Publishing house: Academy of the People's Republic of Romania.

Perumaal, S. and N. Jawahar, 2013. Automated trajectory planner of industrial robot for pick-and-place task. IJARS. DOI: 10.5772/53940

Petrescu, F. and R. Petrescu, 1995a. Contributions to optimization of the polynomial motion laws of the stick from the internal combustion engine distribution mechanism. Bucharest.

Petrescu, F. and R. Petrescu, 1995b. Contributions to the synthesis of internal combustion engine distribution mechanisms. Bucharest.

Petrescu, F. and R. Petrescu, 1997a. Dynamics of cam mechanisms (exemplified on the classic distribution mechanism). Bucharest.

Petrescu, F. and R. Petrescu, 1997b. Contributions to the synthesis of the distribution mechanisms of internal combustion engines with Cartesian coordinate method. Bucharest.

Petrescu, F. and R. Petrescu, 1997c. Contributions to maximizing polynomial laws for the active stroke of the distribution mechanism from internal combustion engines. Bucharest.

Petrescu, F. and R. Petrescu, 2000a. Synthesis of distribution mechanisms by the rectangular (cartesian) coordinate method. University of Craiova, Craiova.

Petrescu, F. and R. Petrescu, 2000b. The design (synthesis) of cams using the polar coordinate method (the triangle method). University of Craiova, Craiova.

Petrescu, F. and R. Petrescu, 2002a. Motion laws for cams. Proceedings of the 7th National Symposium with International Participation Computer Assisted Design, (PAC’ 02), Braşov, pp: 321-326.

Petrescu, F. and R. Petrescu, 2002b. Camshaft dynamics elements. Proceedings of the 7th National Symposium with International Participation Computer Assisted Design, (PAC’ 02), Braşov, pp: 327-332.

Petrescu, F. and R. Petrescu, 2003. Some elements regarding the improvement of the engine design. Proceedings of the 8th National Symposium, Descriptive Geometry, Technical Graphics and Design, (GTD' 03), Braşov, pp: 353-358.

Petrescu, F. and R. Petrescu, 2005a. The cam design for a better efficiency. Proceedings of the International Conference on Engineering Graphics and Design, (EGD' 05), Bucharest, pp: 245-248.

Petrescu, F. and R. Petrescu, 2005b. Contributions at the dynamics of cams. Proceedings of the 9th IFToMM International Symposium on Theory of Machines and Mechanisms, (TMM' 05), Bucharest, Romania, pp: 123-128.

Petrescu, F. and R. Petrescu, 2005c. Determining the dynamic efficiency of cams. Proceedings of the 9th IFToMM International Symposium on Theory of Machines and Mechanisms, (TMM' 05), Bucharest, Romania, pp: 129-134.

Petrescu, F. and R. Petrescu, 2005d. An original internal combustion engine. Proceedings of the 9th IFToMM International Symposium on Theory of Machines and Mechanisms, (TMM' 05), Bucharest, Romania, pp: 135-140.

Petrescu, F. and R. Petrescu, 2005e. Determining the mechanical efficiency of Otto engine's mechanism. Proceedings of the 9th IFToMM International Symposium on Theory of Machines and Mechanisms, (TMM' 05), Bucharest, Romania, pp: 141-146.

Petrescu, F. and V. Petrescu, 2014a. Balancing otto engines. Int. Rev. Mech. Eng., 8: 473-480.

Petrescu, F. and R. Petrescu, 2014b. Determination of the yield of internal combustion thermal engines. Int. Rev. Mech. Eng., 8: 62-67.

Petrescu, F. and R. Petrescu, 2014c. Forces of internal combustion heat engines. Int. Rev. Modell. Simulat., 7: 206-212.

Petrescu, F.I. and R.V. Petrescu, 2013. Cinematics of the 3R Dyad. Engevista, 15: 118-124.

Petrescu, F.I.T. and R.V. Petrescu, 2012a. The Aviation History. Publisher: Books On Demand, ISBN-13: 978-3848230778.

Petrescu, F.I. and R.V. Petrescu, 2012b. Mecatronica-Sisteme Seriale si Paralele. Create Space Publisher, USA, ISBN-10: 978-1-4750-6613-5, pp: 128.

Petrescu, F.I. and R.V. Petrescu, 2011. Mechanical Systems, Serial and Parallel-Course (in Romanian). LULU Publisher, London, UK, ISBN-10: 978-1-4466-0039-9, pp: 124.

Petrescu, F.I. and R.V. Petrescu, 2016a. Parallel moving mechanical systems kinematics, ENGEVISTA, 18: 455-491.

Petrescu, F.I. and R.V. Petrescu, 2016b. Direct and inverse kinematics to the Anthropomorphic Robots, ENGEVISTA, 18: 109-124.

Petrescu, F. and R. Petrescu, 2016c. An otto engine dynamic model. IJM&P, 7: 038-048.

Petrescu, F.I. and R.V. Petrescu, 2016d. Otto motor dynamics, GEINTEC, 6: 3392-3406.

Petrescu, F.I. and R.V. Petrescu, 2016e. Dynamic cinematic to a structure 2R. GEINTEC, 6: 3143-3154.

Petrescu, F.I., B. Grecu, A. Comanescu and R.V. Petrescu, 2009. Some mechanical design elements. Proceeding of the International Conference on Computational Mechanics and Virtual Engineering, (MEC' 09), Braşov, pp: 520-525.

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and F.I.T. Petrescu, 2016a. About the gear efficiency to a simple planetary train. Am. J. Applied Sci., 13: 1428-1436.

Petrescu, R.V., R. Aversa, A. Apicella, S. Li and G. Chen *et al*., 2016b. Something about electron dimension. Am. J. Applied Sci., 13: 1272-1276.

Petrescu, F.I.T., A. Apicella, R. Aversa, R.V. Petrescu and J.K. Calautit *et al*., 2016c. Something about the mechanical moment of inertia. Am. J. Applied Sci., 13: 1085-1090.

Petrescu, R.V., R. Aversa, A. Apicella, F. Berto and S. Li *et al*., 2016d. Ecosphere protection through green energy. Am. J. Applied Sci., 13: 1027-1032.

Petrescu, F.I.T., A. Apicella, R.V. Petrescu, S.P. Kozaitis and R.B. Bucinell *et al*., 2016e. Environmental protection through nuclear energy. Am. J. Applied Sci., 13: 941-946.

Petrescu, F.I.T. and J.K. Calautit, 2016a. About nano fusion and dynamic fusion. Am. J. Applied Sci., 13: 261-266.

Petrescu, F.I.T. and J.K. Calautit, 2016b. About the light dimensions. Am. J. Applied Sci., 13: 321-325.

Petrescu, R.V., R. Aversa, B. Akash, R. Bucinell and J. Corchado *et al*., 2017a. Modern propulsions for aerospace-a review. J. Aircraft Spacecraft Technol., 1: 1-8. DOI: 10.3844/jastsp.2017.1.8

Petrescu, R.V., R. Aversa, B. Akash, R. Bucinell and J. Corchado *et al*., 2017b. Modern propulsions for aerospace-part II. J. Aircraft Spacecraft Technol., 1: 9-17. DOI: 10.3844/jastsp.2017.9.17

Petrescu, R.V., R. Aversa, B. Akash, R. Bucinell and J. Corchado *et al*., 2017c. History of aviation-a short review. J. Aircraft Spacecraft Technol., 1: 30-49. DOI: 10.3844/jastsp.2017.30.49

Petrescu, R.V., R. Aversa, B. Akash, R. Bucinell and J. Corchado *et al*., 2017d. Lockheed martin-a short review. J. Aircraft Spacecraft Technol., 1: 50-68. DOI: 10.3844/jastsp.2017.50.68

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017e. Our universe. J. Aircraft Spacecraft Technol., 1: 69-79. DOI: 10.3844/jastsp.2017.69.79

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017f. What is a UFO? J. Aircraft Spacecraft Technol., 1: 80-90. DOI: 10.3844/jastsp.2017.80.90

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017g. About bell helicopter FCX-001 concept aircraft-a short review. J. Aircraft Spacecraft Technol., 1: 91-96. DOI: 10.3844/jastsp.2017.91.96

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017h. Home at airbus. J. Aircraft Spacecraft Technol., 1: 97-118. DOI: 10.3844/jastsp.2017.97.118

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017i. Airlander. J. Aircraft Spacecraft Technol., 1: 119-148. DOI: 10.3844/jastsp.2017.119.148

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017j. When boeing is dreaming-a review. J. Aircraft Spacecraft Technol., 1: 149-161. DOI: 10.3844/jastsp.2017.149.161

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017k. About Northrop Grumman. J. Aircraft Spacecraft Technol., 1: 162-185. DOI: 10.3844/jastsp.2017.162.185

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017l. Some special aircraft. J. Aircraft Spacecraft Technol., 1: 186-203. DOI: 10.3844/jastsp.2017.186.203

Petrescu, R.V., R. Aversa, B. Akash, J. Corchado and F. Berto *et al*., 2017m. About helicopters. J. Aircraft Spacecraft Technol., 1: 204-223. DOI: 10.3844/jastsp.2017.204.223

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017n. The modern flight. J. Aircraft Spacecraft Technol., 1: 224-233. DOI: 10.3844/jastsp.2017.224.233

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017o. Sustainable energy for aerospace vessels. J. Aircraft Spacecraft Technol., 1: 234-240. DOI: 10.3844/jastsp.2017.234.240

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017p. Unmanned helicopters. J. Aircraft Spacecraft Technol., 1: 241-248. DOI: 10.3844/jastsp.2017.241.248

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017q. Project HARP. J. Aircraft Spacecraft Technol., 1: 249-257. DOI: 10.3844/jastsp.2017.249.257

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017r. Presentation of Romanian engineers who contributed to the development of global aeronautics-part I. J. Aircraft Spacecraft Technol., 1: 258-271. DOI: 10.3844/jastsp.2017.258.271

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017s. A first-class ticket to the planet mars, please. J. Aircraft Spacecraft Technol., 1: 272-281. DOI: 10.3844/jastsp.2017.272.281

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017t. Forces of a 3R robot. J. Mechatron. Robot., 1: 1-14. DOI: 10.3844/jmrsp.2017.1.14

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017u. Direct geometry and cinematic to the MP-3R systems. J. Mechatron. Robot., 1: 15-23. DOI: 10.3844/jmrsp.2017.15.23

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017v. Dynamic elements at MP3R. J. Mechatron. Robot., 1: 24-37. DOI: 10.3844/jmrsp.2017.24.37

Petrescu, R.V., R. Aversa, B. Akash, F. Berto and A. Apicella *et al*., 2017w. Geometry and direct kinematics to MP3R with 4×4 operators. J. Mechatron. Robot., 1: 38-46. DOI: 10.3844/jmrsp.2017.38.46

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017x. Current stage in the field of mechanisms with gears and rods. J. Mechatron. Robot., 1: 47-57. DOI: 10.3844/jmrsp.2017.47.57

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017y. Geometry and inverse kinematic at the MP3R mobile systems. J. Mechatron. Robot., 1: 58-65. DOI: 10.3844/jmrsp.2017.58.65

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017z. Synthesis of optimal trajectories with functions control at the level of the kinematic drive couplings. J. Mechatron. Robot., 1: 66-74. DOI: 10.3844/jmrsp.2017.66.74

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017aa. The inverse kinematics of the plane system 2-3 in a mechatronic MP2R system, by a trigonometric method. J. Mechatron. Robot., 1: 75-87. DOI: 10.3844/jmrsp.2017.75.87

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017ab. Serial, anthropomorphic, spatial, mechatronic systems can be studied more simply in a plan. J. Mechatron. Robot., 1: 88-97. DOI: 10.3844/jmrsp.2017.88.97

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017ac. Analysis and synthesis of mechanisms with bars and gears used in robots and manipulators. J. Mechatron. Robot., 1: 98-108. DOI: 10.3844/jmrsp.2017.98.108

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017ad. Speeds and accelerations in direct kinematics to the MP3R systems. J. Mechatron. Robot., 1: 109-117. DOI: 10.3844/jmrsp.2017.109.117

Petrescu, R.V., R. Aversa, A. Apicella, M.M. Mirsayar and S. Kozaitis *et al*., 2017ae. Geometry and determining the positions of a plan transporter manipulator. J. Mechatron. Robot., 1: 118-126. DOI: 10.3844/jmrsp.2017.118.126

Petrescu, R.V., R. Aversa, T. Abu-Lebdeh, A. Apicella and F.I.T. Petrescu, 2018. Kinematics of a mechanism with a triad. Am. J. Eng. Applied Sci., 11: 297-308. DOI: 10.3844/ajeassp.2018.297.308

Reddy, P., K.V. Shihabudheen and J. Jacob, 2012. Precise non linear modeling of flexible link flexible joint manipulator. IReMoS, 5: 1368-1374.

Sevil, H.E and A. Dogan, 2015. Fault diagnosis in air data sensors for receiver aircraft in aerial refueling. J. Guidance Control Dynam., 38: 1959-1975. DOI: 10.2514/1.G000527

Sherson, J.F., H. Krauter, RK. Olsson, B. Julsgaard and K. Hammerer *et al*., 2006. Quantum teleportation between light and matter. Nature, 443: 557-560. DOI: 10.1038/nature05136

Sun, J.Z. and S.M. Joshi, 2009. An indirect adaptive control scheme in the presence of actuator and sensor failures. Proceedings of the AIAA Guidance, Navigation and Control Conference, Aug. 10-13, Chicago, Illinois. DOI: 10.2514/6.2009-5740

Taković, S., M. Zeljković, R. Gatalo and A. Živković, 2013. Program suite for conceptual designing of parallel mechanism-based robots and machine tools. Int. J. Adv. Robot Syst. DOI: 10.5772/56633

Tang, X., D. Sun and Z. Shao, 2013. The structure and dimensional design of a reconfigurable PKM. IJARS. DOI: 10.5772/54696

Tabaković, S., M. Zeljković, R. Gatalo and A. Živković, 2013. Program suite for conceptual designing of parallel mechanism-based robots and machine tools. Int. J. Adv. Robot Syst. DOI: 10.5772/56633

Tang, X., D. Sun and Z. Shao, 2013. The structure and dimensional design of a reconfigurable PKM. IJARS. DOI: 10.5772/54696

Tong, G., J. Gu and W. Xie, 2013. Virtual entity-based rapid prototype for design and simulation of humanoid robots. Int. J. Adv. Robot. Syst. DOI: 10.5772/55936

Venkataraman, G., 1992. Chandrasekhar and his Limit. 1st Edn., Universities Press, ISBN-10: 817371035X, pp: 89.

Wang, K., M. Luo, T. Mei, J. Zhao and Y. Cao, 2013. Dynamics analysis of a three-DOF planar serial-parallel mechanism for active dynamic balancing with respect to a given trajectory. Int. J. Adv. Robotic Syst. DOI: 10.5772/54201

Williams, D.R., 1995. Saturnian satellite fact sheet. NASA.

Wen, S., J. Zhu, X. Li, A. Rad and X. Chen, 2012. End-point contact force control with quantitative feedback theory for mobile robots. IJARS. DOI: 10.5772/53742