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CONCENTRATION OF MOVEMENTS ON THE LINKS OF MANIPULATION SYSTEMS FOR ROBOTS

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Introduction

The robots have entered into their "ripe age" and have proved their right of real existence. Even the most sceptical people cannot deny the effective application of the robots in a significant number of the human activities. The robots have established in the industry as perfect operators of supplementary and basic technological operations. Especially rational is their application under unhealthy and dangerous conditions of work. As an analogue of the human being in the nonlive nature (robot-"Iron human"), in "their evolution", the robots have to find equal qualities as the human ones. One of the directions of the evolution development of the robots is the increase of the mobility of the manipulation systems (MS). The other one is improving the manipulative qualities in the framerowk of the working area. These qualities could not be achieved by the used methods for construction of robots.

1. Motives for the concentration of movements on the links

It is known that the structures of manipulation systems of open, closed and mixed type, used today, are built up mainly on the basis of five class kinematic pairs-rotational (R) and translational (T), situated orthogonally each to other. In some structures for local movements, it happens nonorthogonal position of the pairs (wrist of robot KUKA).

The maximum number of degrees of mobility, applied widely by the firms producers of robots is between 5 and 7. They are enough for solving a wide class of tasks and at the same time few in comparison with the human-operator ones. The increase of the degrees of mobility of the robots is a necessity without alternative. The solution of the problem with the accepted means leads to increase of the number of the mobile links and kinematic pairs, which under other equal conditions diminish the load capacity and the pose accuracy, make worse the dynamic and vibration qualities of the MS. Some part of those problems are solved by: application of closed

contours, suitable situated in the structure; application of materials with small mass and high mechanical strength: pre-stressed constructions, precise bearings, guiding and transmission mechanisms, control devices, reading the real movement of the MS and inserting the necessary correction. The effect of all these means would be greater if the raise of the degrees of mobility of the MS is done not the increase of the number of the mobile links, but by the increase of the movements of less mobile links, i. e. concentration of more movements on the links. This is equal to reduce the class of the kinematic pairs between the mobile links.

2. Systematics of the kinematic pairs. Kinematic joints

The concentration of movements on the links needs a new view, concerning the kinematic pairs. On the basis of the classical approach for forming elementary relative movements between the links, a systematical search of the possible solutions has to be done. On the other hand, creation of a new type mobile kinematic joints between two and more links is necessary, which gives the possibility for complex spatial movements.

The elementary movements, rotation (R) and translation (T), determine regular geometrical shapes of the surfaces, on which the two links forming a kinematic pair are in contact. These surfaces are a restricted multitude. The elementary five class pairs can be zealized constructively in this multitude in different way [5]. The kinematic pairs obtained from the types and the combinations of the elementary movements are shown in Table 1. In the table it is accepted that two and three movements of one and the same type are perpendicular mutually. For the different type of movements, perpendicular ($\perp$) and coaxial (Z) mutual situation is combined. These combinations have sense only for two or three elementary movements, because for more by permutation it is obtained always one of the two combinations. As the choice of continuity of elementary movements for the kinematic pairs is free, the permutations are not shown.

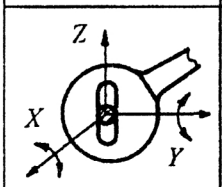
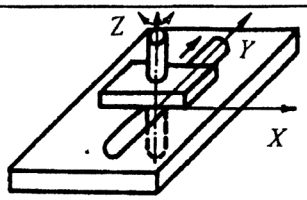
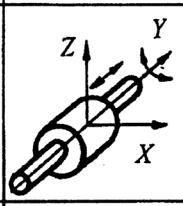
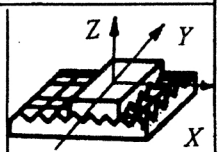
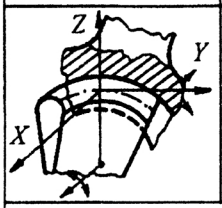
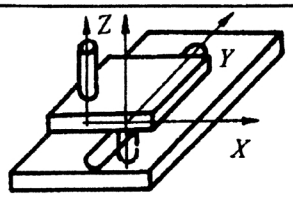
Table 1. Kinematic pairs, obtained by the type and the combination of elementary movements

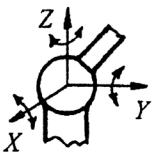
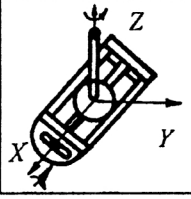
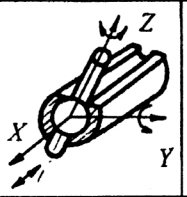
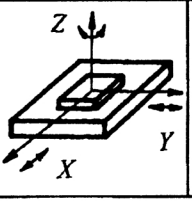
CLASS OF THE KINEMATIC PAIR	TYPE AND COMBINATION OF ELEMENTARY MOVEMENTS	MUTUAL POSITION
P5	*RT*	
P4	*RR* *RT* *TT*	*R ⊥ T; RzT*
P3	*RRR* *RRT* *TTR* *TTT*	*RR ⊥ T; RRzT* *TT ⊥ R; TTzR*
P2	*RRRT* *RRTT* *TTTR*	
P1	*RRRTT* *TTTRR*	

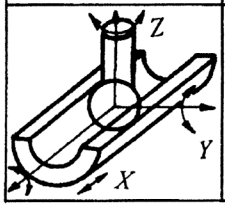
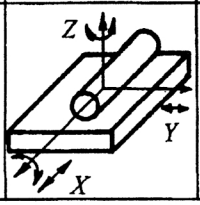
In Table 2 some geometrical solutions for kinematic pairs are given. Two mutual perpendicular translations have been difficult zealized geometrically, and in case of three translations, the author has not found solution yet.

For the relative movement between the links, it is typical the angle of rotation to be smaller than 360°. Hence, the need for application of surfaces with axes of symmetry doesn't exist. Apart from this by analogy with the limbs of the human, the typical

Table 2. Some geometrical solutions of kinematic pairs

P4			
RR	R ⊥ T	R z T	TT
			
			

P3					
RRR	RR z T	RR ⊥ T	TT ⊥ R	TT z R	TTT
					

P2			
RRRT	Tz RR z T	T z RR ⊥ T	TTTR
			

combinations of the movements can be made, according to the position of the pair in the MS and it specializes the form, which in the case of complex spatial movements is 3-D surface.

The contemporary technological machines with CNC control, allow performance of complex 3-D surfaces at high accuracy, and thus the technological restriction for elementary surfaces drops out.

According to the author, the necessity of intermediate rolling parts in the kinematic pairs drops out, because of the occurring great contact deformations. Reduction of the friction at the existing restrictions will be achieved with other means (electro-magnetic, hydrostatic and gasstatic). When more complex contours (mechanisms) in the MS are used, the application of more than two links is needed. Such solutions are implemented in the known structures (kinematic joints of three and more links).

Other arguments for establishing the term kinematic (movable) joint, which is opposite to the static joint between the bodies can be given.

3. Examples for manipulation systems with concentration of movements

The concentration of movements on the links of the MS must not be a task as an end in itself. The type, quantity and the orientation of the elementary movements has to be well-grounded functionally. On the one hand, according to the shape and the position of the working area, and on the other hand, achievement of some qualitative indices in it. For that purpose, it is necessary to do a system search for the optimal movements during the performance of object (technological) task. Hence, structures, which realize the typical movements, have to be found.

The given example solutions have been illustrated the approach. The full possibilities will be revealed when constructing new type kinematic joints and "driving devices", which are correspoding with them. The new type kinematic joints are base for creation of new structures of MS. As that is still a perspective, the illustration is made with conventional drives.

In Fig. 1a and 1b, kinematic schemes of modules with two degrees of mobility, type *RzT* are shown. The schemes are realized on the basis of differential screw mechanism [3]. The end-effector performs screw motion in the general case. The connection between the displacement of the end-effector S and the angles of rotation of the screw φ_1 and of the rack is given by the expression:

$$S = P / 2\pi.\left(i_{11'}.\varphi_{M1} - i_{22'}.\varphi_{M2}\right) \tag{1}$$

where: P is the step of the screw: φ_{M1} and φ_{M2} are the angles of rotation of the actuators $M1$ and $M2$: $i_{11'}=z_{1'}/z_1'$, $i_{22'}=z_2/z_{2'}$ are the transmisson ratios, determining the connection between φ_{M1} and φ_1, φ_{M2} and φ_2.

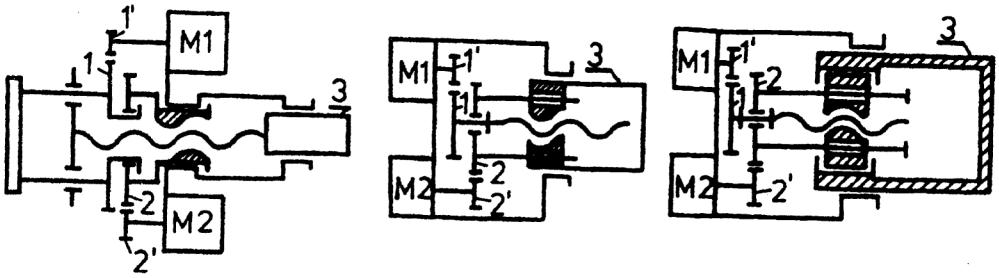


Fig. 1. Kinematic scheme of differential screw mechanisms
a) rotation and translation of the screw
b) rotation and translation of the rack
c) displacement of link 3

In the particular cases the schemes allow:

$$\text{(2)}\quad \begin{aligned} &\text{a)}\ S=0;\ \ \varphi_{M1}=i_{22'}\cdot\varphi_{M2}/i_{11'}\cdot \\ &\text{b)}\ \varphi_2=0;\ \ S=P/2\pi.(i_{11'}\cdot\varphi_1). \end{aligned}$$

The modificated scheme (Fig. 1c), allows achievement of high kinematic effect, even at equal angles $\varphi_{M1}=\varphi_{M2}$ (actuating from one motor). With the modules, shown in Fig. 1a and 1b, can be built regional structures of MS, illustrated in Fig. 2.

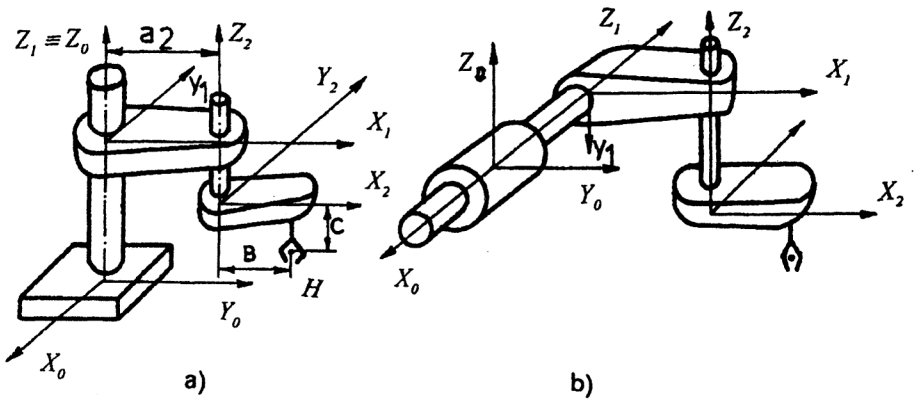


Fig. 2. Regional structures with $P4$ ($R \perp T$) kinematic pairs
a) scheme type SCARA
b) scheme $R_x\ T_x\ R_z\ T_z$

The scheme from Fig. 2a is functionally analogical with the SCARA type robots, but the moving links here are two, and the degrees of mobility-four.

As the output links realize screw motion, there is a particularity in the kinematic analysis by the method of Denavit and Hartenberg. The relative motion between the links at the conventional application of the method is described by [2]:

$$R_{i-1}=A_i \,.\, R_i \tag{3}$$

where: $R_i=(x_i,\ y_i,\ z_i,\ 1)^T$ is a vector determining the co-ordinates of a point in the i^{th} co-ordinate system, A_i - 4×4 matrix consisting of one variable.

In this case (Fig. 2a), the matrices A_i consist of two variables θ_i and S_i (i=1, 2). For the scheme in Fig. 2a, the parameters of Denavit and Hartenberg are the following:

Table 3. Denavit and Hartenberg parameters

LINK	α	*a*	*S*	θ
1	0	0	S_1	θ_1
2	0	a_2	S_2	θ_2

For the matrices A_i it is obtained:

$$A_1=\begin{vmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & S_1 \\ 0 & 0 & 0 & 1 \end{vmatrix},\quad A_2=\begin{vmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & a_2.\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & a_2.\sin\theta_2 \\ 0 & 0 & 1 & S_2 \\ 0 & 0 & 0 & 1 \end{vmatrix}. \tag{4}$$

The co-ordinates of some points with respect to the basic co-ordinate system (x_0, y_0, z_0) are determined by the vector $R_{0i}=(x_{0i}, y_{0i}, z_{0i}, 1)^T$, which value is given by [2]:

$$R_{0i}=T_i R_i. \tag{5}$$

In this case, the matrices T_i (i=1,2) are equal:

(6)

$$T_1=\begin{vmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & S_1 \\ 0 & 0 & 0 & 1 \end{vmatrix},\quad T_2=\begin{vmatrix} \cos(\theta_1+\theta_2) & -\sin(\theta_1+\theta_2) & 0 & a_2.\cos(\theta_1+\theta_2) \\ \sin(\theta_1+\theta_2) & \cos(\theta_1+\theta_2) & 0 & a_2.\sin(\theta_1+\theta_2) \\ 0 & 0 & 1 & S_2+S_2 \\ 0 & 0 & 0 & 1 \end{vmatrix}.$$

The co-ordinates of the characteristic point H with respect to the basic co-ordinate system under the condition $X_{2H}=b$, $Y_{2H}=0$, $Z_{2H}=C$, are obtained by the expressions:

$$\begin{aligned} X_{0H} &= b.\cos(\theta_1+\theta_2)+a_2.\cos(\theta_1+\theta_2) \\ Y_{0H} &= b.\sin(\theta_1+\theta_2)+a_2.\sin(\theta_1+\theta_2) \\ Z_{0H} &= S_1+S_2+C. \end{aligned} \tag{7}$$

When we have to differentiate the matrices A_i we exercise multiplication:

$$\frac{\partial A_i}{\partial q_i} = \theta_B . A_i, \quad \text{where: } \theta_B = \begin{vmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{vmatrix}. \tag{8}$$

The exploration of the example, illustrated in Fig. 2b can be fulfilled by analogical way.

4. Conclusion

The concentration of elementary movements on the links of the MS give a possibility for reducing the number of the mobile links, which under other equal conditions improves the dynamic attitude of the robot. Another positive effect is the increasing of the manipulative resources (co-efficient of service) in the framework of the working area. All the examples illustrated in the paper, confirm the expressed suppositions.

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Acknowledgements

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