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STRUCTURAL SYNTHESIS FOR REDUNDANT INDUSTRIAL ROBOTS WITH MORE 6 AXES

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Abstract: *This paper presents the most possible structures with 7 or 8 axes, which correspond to non-degenerate workspaces of which one can choose other variants than existing ones, to be manufactured. Structures of kinematic chains with more of 8 axes can be obtained from 6-axis ones, by adding three axes (three monomobile kinematic couplings) of rotation or translation or combined RRR, respectively, TTT, than by adding four axes, five axes or six axes. Some of these structures may have specific functional advantages in certain situations, which will be validated for sure by future practical applications. Redundant kinematic chains with 7 or 8 axes (7 or 8 monomobile rotation or translation couplings) or more axes, but not more 12 axes, have proved to be useful and some variants are already applied in some industrial robots already existing in practice. In the next papers representation of workspace helps the designer to choose structures that may have a high degree of functionality for a given range of applications. Kinematic analysis based on the method of homogeneous operators exemplifies the possibility to resolve this issue in the case of these redundant robots too.*
Keywords: *redundant robot, structural systematization, kinematic chain*

1. INTRODUCTION

According to generally accepted principles, a serial industrial robot kinematic chain must have 6 axes (3 axes corresponding to the positioning kinematic chain and 3 axes corresponding to the orientation kinematic chain), any additional number of axes (monomobile kinematic couplings), leading to a certain redundancy. First, it was considered that redundant kinematic chains are not desirable because they increase the complexity unnecessarily, leading to more time to calculate trajectories and to higher costs. In recent years, there have been attempts to promote and even make industrial robots with redundant serial kinematic chains, especially those with 7 axes, but also with 8 axes [1],[2],[3],[4],[5],[6],[7],[8],[9]. They prove to have larger workspaces and more handling possibilities within these areas. The early disadvantages mentioned have reduced their importance significantly, by increasing the calculation speed of trajectories due to existing processors' calculation power boost and lower design and manufacturing costs. Under these new conditions, a 7-axis structure, or structure with more 7 axes relatively more complicated, has become a very important functional advantage for a robot. To provide a useful tool, including for the promotion of new redundant structures, except existing ones, which are applied, in this paper there is a synthesis of kinematic chain structures with 7 axes, 8 axes and more.

2. STRUCTURAL SYNTHESIS OF SERIAL KINEMATIC CHAINS WITH 7 AXES FOR ROBOTS

According to [10], there are some serial kinematic chain structures with 6 axes for robots, with non-degenerated workspaces (reduced to a line or an area) which are usable. They are obtained identifying possible combinations between 3 rotation axes (monomobile couplings), respectively translation (RRR-TTT), considering only situations when two successive couplings are perpendicular or parallel, for positioning kinematic chains, considering possible eccentricities that equals or not zero and of 3 axes (monomobile couplings) of rotation (RRR), corresponding to the orientation kinematic chain. We consider only structures corresponding to non-degenerated workspaces. They are structures whose relative positions of successive couplings are perpendicular or parallel because these structures are more frequently applied to industrial robots and they are validated in practice as the most functional.

Structures with 7 axes (monomobile kinematic chains) are obtained from 6-axis ones adding a monomobile kinematic rotation coupling (R) or translation coupling (T), also in a relative position, perpendicular or parallel with the anterior or posterior coupling. Obviously, for each structure, the corresponding workspace is generated and we only consider those corresponding to non-degenerated workspaces. Basic versions are obtained if the eccentricity between two successive couplings equals zero, and derived versions if the eccentricity is not zero, developed along an axis, two axes, or three axes. Thus, according to [10], there are 20 different structures of tri-mobile positioning kinematic chains, generating volume-non-degenerated workspaces and 8 tri-mobile orientation kinematic chain structures. In Fig. 1 there are 2 examples of positioning kinematic chains highlighting significant kinematic parameters: a_1, a_2,d, r,S_O ,S and M-is the characteristic point of the robot extremity [10].

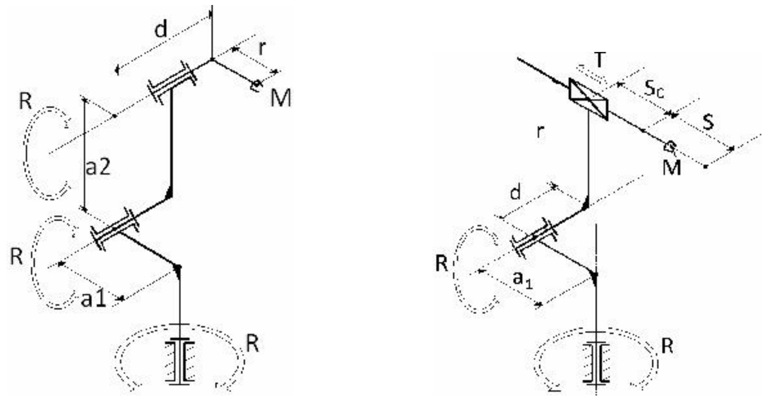


Figure 1: Two examples of tri-mobile positioning kinematic chains: R⊥R||R(a), R⊥R⊥T(b)

In Fig. 2 there are two examples of orientation kinematic chains (made of 3 rotation couplings -R⊥R⊥R; a,b – geometric parameters; l,n – the gripper position, longitudinal or perpendicular to the last axis of the orientation mechanism; for version b : a=0)[10]. Connecting in series a positioning kinematic chain with an orientation kinematic chain, we obtain the guiding kinematic chain, in this case having six axes (six monomobile rotation or translation kinematic couplings), where two successive axis-couplings are perpendicular (⊥) or parallel (||).

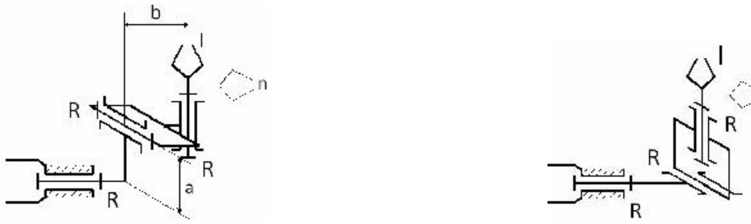
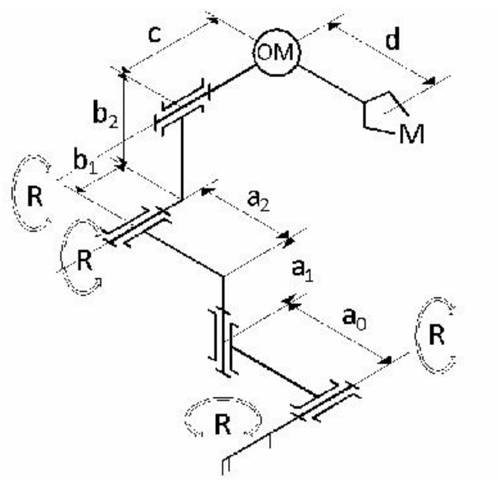
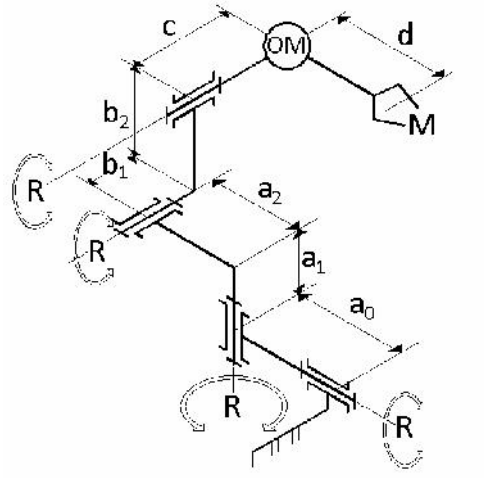


Figure2: Two examples of tri-mobile orientation kinematic chains: R⊥R⊥R

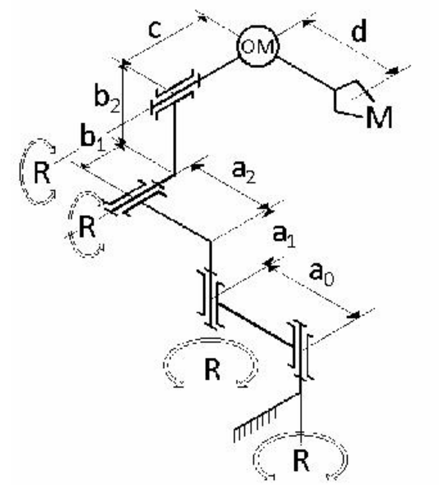
Guiding kinematic chains with seven axes (seven monomobile kinematic couplings of rotation or translation, positioned relatively perpendicular or parallel) we obtain out of those of six axes adding one monomobile kinematic coupling (an additional axis) of rotation (R) or translation (T). This coupling can be added at the beginning, at the end of the guiding kinematic chain or between the two component kinematic chains. To obtain all the possible combinations, without losing the positioning kinematic chain and the orientation kinematic chain functionality, we consider the positioning kinematic chain a different kinematic module called positioning kinematic module (MP) and the orientation kinematic chain called orientation kinematic module (MO). The relative position of the seventh coupling (axis) to the first or last coupling of one of the two modules can be perpendicular (⊥) or parallel (||). We obtain 12 possible combinations for each structure with 6 axes(see e.g. Fig.3): R⊥(MP)(MO)- a1,a2, R||(MP) (MO)-b, T⊥(MP)(MO)-c1,c2, T||(MP)(MO)-d, (MP)⊥R(MO)-e, (MP)||R(MO)-f, (MP)⊥T(MO)-g, (MP)||T(MO)-h, (MP)(MO)⊥R-i, (MP)(MO)||R-j. (MP)(MO)⊥T-k, (MP)(MO)||T-l. There are altogether, for the 20 structures with 6 axes, 240 structures with 7 axes. In Fig. 3 there are the 12 kinematic versions with seven axes, representing in detail the positioning module, type: R⊥R⊥T and the compact version of the orientation module (R⊥R⊥R). Notations represent: T,R- monomobile translation couplings, respectively rotation couplings; $a_0, a_1, a_2, b_1, b_2, b_3$, c, c_1, c_2, c_3, d-significant kinematic parameters, and M is the characteristic point of the robot. We note that in case of the perpendicular position of the axis, there are, in general, two versions: the first perpendicular along the direction between the two axes (as in the case in Fig. 3a1, and the second collinear with the direction between the two axes,see e. g. Fig.3a2, versions that will be detailed in following papers).



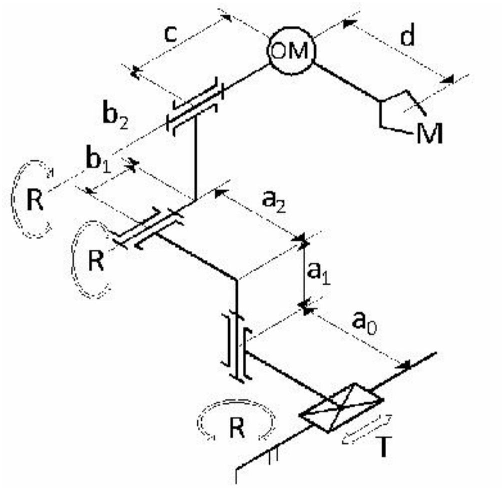
a1



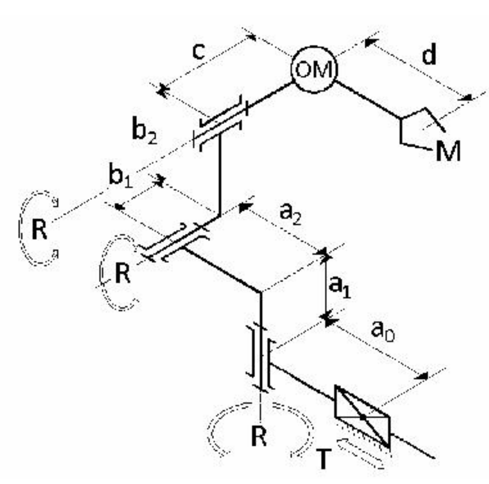
a2



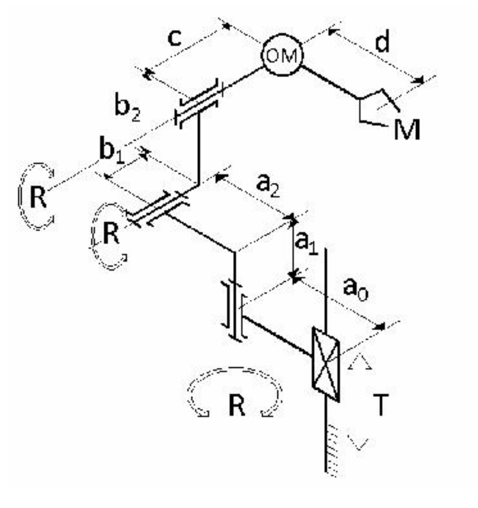
b



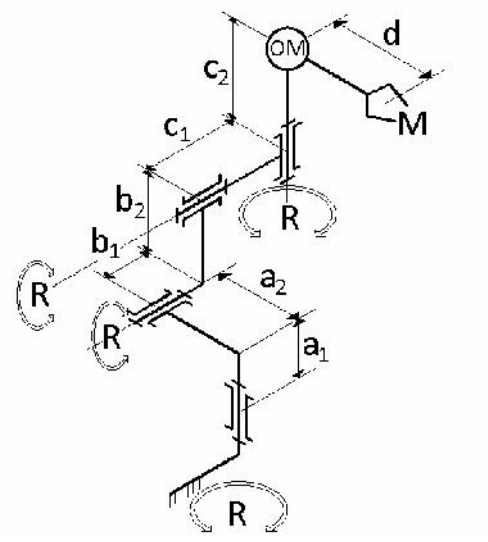
c1



c2



d


c_2
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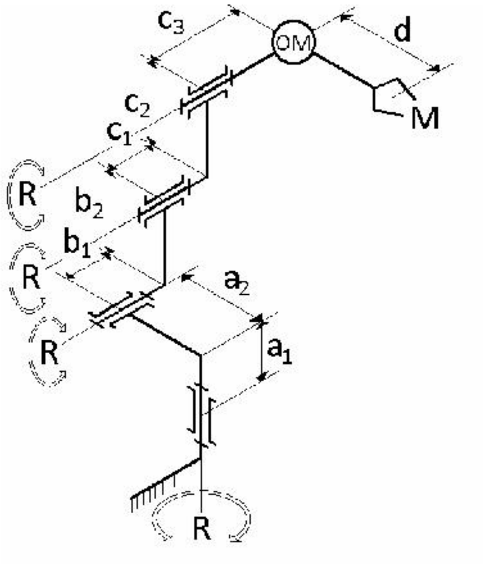
c_3
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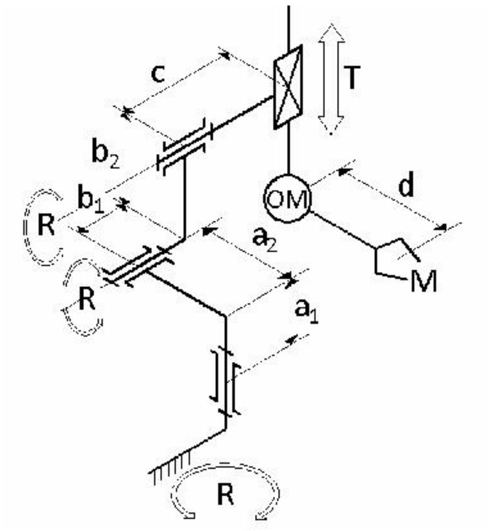
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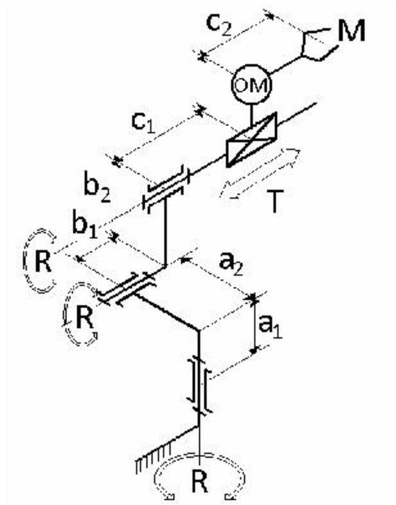
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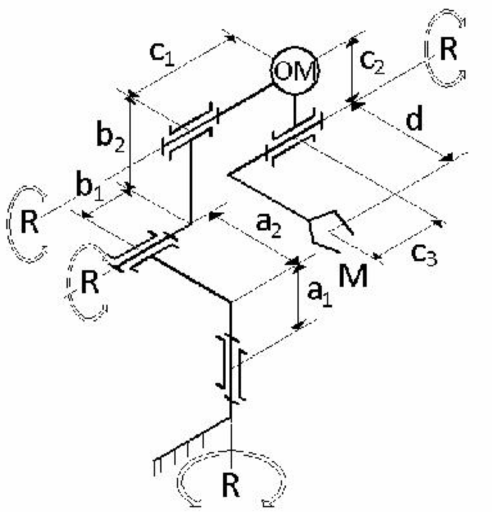
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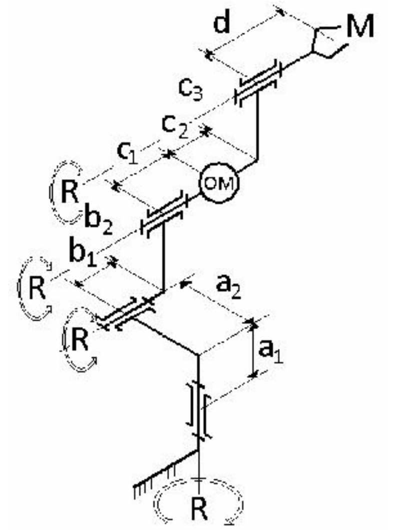
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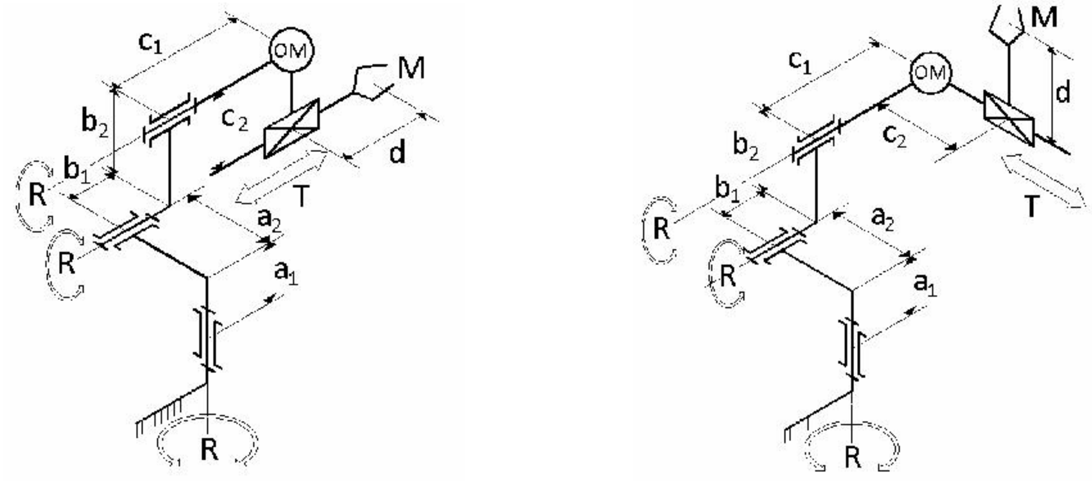
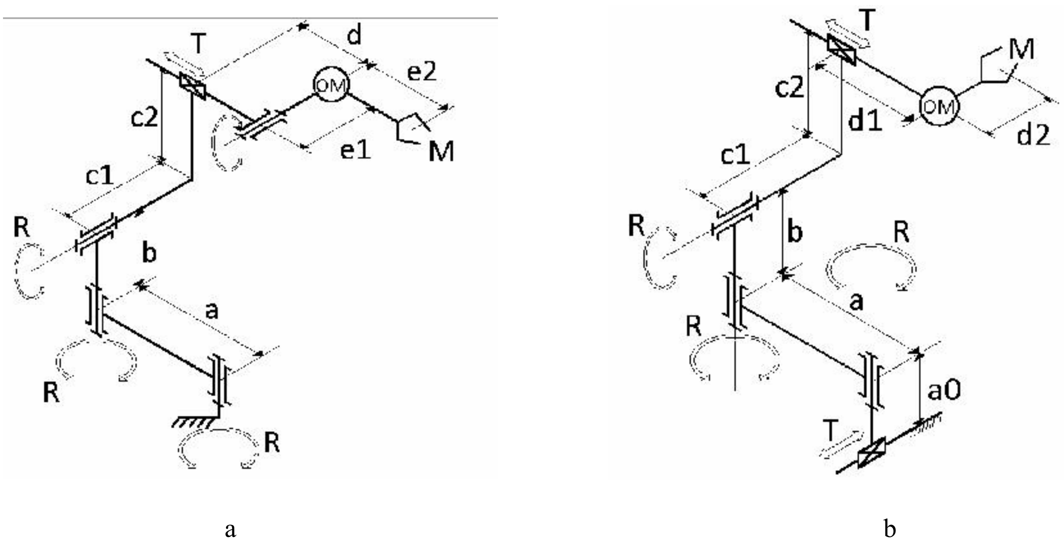


k l

Figure 3: Guiding kinematic chains with seven axes

3. STRUCTURAL SYSTEMATIZATION OF KINEMATIC CHAINS WITH 8 AXES FOR ROBOTS

Structures of kinematic chains with 8 axes can be obtained from 6-axis ones, by adding two axes (two monomobile kinematic couplings) of rotation or translation or combined RT, respectively, TR. They can be both at one end of the 6-axis kinematic chain, or one at one end and the other at the other end of the said kinematic chain, or by adding R or T axes to 7-axis structures. This additional axis is added similarly to the case of obtaining structures with 7 axes out of 6-axis ones. Therefore, we obtain a number of distinct structures corresponding to nondegenerate workspaces. Thus by adding a rotation (R) or translation (T) coupling, perpendicular (⊥) or parallel (||) to the first four structures (R/T)(⊥/||)(PM)(OM) of the seven-axis kinematic chain, we obtain 16 8-axis kinematic chain structures:R⊥R⊥(PM)(OM),...,T||T||(PM)(OM).Similarly, we obtain structural variants with eight axes based on 7-axis structures such as: (PM)(⊥/||)(R/T)(OM) and (PM)(OM)(⊥/||)(R/T). There are 96 final versions, 16 for each combination: (R/T)(⊥/||)(R/T)(⊥/||)(PM)(OM), (R/T)(⊥/||)(PM)(⊥/||)(R/T)(OM), (R/T)(⊥/||)(PM)(OM)(⊥/||)(R/T), (PM)(⊥/||)(R/T)(OM)(⊥/||)(R/T), (PM)(⊥/||)(R/T)(⊥/||)(R/T)(OM) and (PM)(OM)(⊥/||)(R/T)(⊥/||)(R/T). In Fig. 4 are two kinematic structures with 8 axes with representation in detail of the positioning module structure and brief representation of the orientation module. Corresponding structural diagrams can be represented for all the 96 different possible combinations.



a b

Figure 4: Structural diagrams of two types of kinematic chains with 8 axes

4. STRUCTURAL SYSTEMATIZATION OF KINEMATIC CHAINS WITH MORE OF 8 AXES FOR ROBOTS

It is noted that in a similar way you can obtain redundant structures that can be used in industrial robots with more than 8 axes: 9, 10, 11 or even 12 axes.
Structures of kinematic chains with more of 8 axes can be obtained from 6-axis ones, by adding three axes (three monomobile kinematic couplings) of rotation or translation or combined from RRR, respectively, till TTT(RRR, RRT, RTR, TRR, RTT, TRT, TTR, TTT), than by adding four axes(RRRR, RRRT, RRTR,..., TTTR, TTTT), five axes(RRRRR, RRRRT, RRRTT,...,TTTTT) or six axes(RRRRRR, RRRRRT, RRRTRR, ...,TTTTTT). Some of these structures may have specific functional advantages in certain situations, which will be validated for sure by future practical applications. A number higher than 12 axes already approaches the robotic trunk like structure formed by linking in a row several identical or similar constructive modules [10]. So robots with more twelve axes(six plus six axes) formed vertebrate or robots type trunk.

5. CONCLUSIONS

Redundant kinematic chains with 7 or 8 axes (7 or 8 monomobile rotation or translation couplings) have proved to be useful and some variants are already applied in some industrial robots already existing in practice.
This paper illustrates a method to obtain 12 possible structures with 7 axes, for each structure with 6 axes, with the axes in perpendicular or parallel relative positions, corresponding to non-degenerate workspaces, out of which other versions can be chosen, different from existing ones, to be manufactured. Than the paper shown the method for to obtain the structures with 8 axes and more than 8 axes. Of course, the workspaces representation helps the designer to choose that structure, which can have maximum functionality degree for a given range of applications. These aspect will be topic in the next papers. The structural synthesis method and the method of redundant serial kinematic chains with 7 axes representation can be extrapolated to structures with 8 axes, 9, 10, 11, even 12 axes.

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