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STRUCTURAL SYNTHESIS OF SERIAL SPHERICAL MANIPULATORS

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Abstract: Serial manipulators are a serial of links connected by joints. The manipulator is called serial, because the drives of this manipulator are arranged in series, one after the other. Most often, the drives of the sequential manipulator are located on jointes or are coordinated with the joint. All links, the base, as well as the executive link, make up the kinematic chain of the manipulator. Serial manipulators have a large working area, it is much larger than the working area of parallel manipulators, which allows them to work with large parts, which undoubtedly increases the area in which the manipulator is capable of working.

Mass-produced robots typically have six joints because at least six degrees of freedom are required to place a controlled object in an arbitrary position and orientation in the robot's workspace. The inverse kinematics of sequential manipulators with six rotary joints and with three consecutive intersecting joints can be solved in closed form, i.e. analytically This result had a huge impact on the design of industrial robots.

This section provides a unified work for the calculation of the mobility and constraints in a general over constraint spherical manipulators based on spherical serial manipulator plus the different spherical structural groups with two, three and four classes. The results of the section can be considered by knowledges of structural groups with general constraint three constructed to the serial spherical manipulator with 3DoF. The 3DoF serial spherical manipulators represent as a series of 1DoF revolute joints with the axises intersecting in the center of sphere. Three illustrative examples showcasing the method are presented.

Keywords: *Serial spherical manipulator, end effector, spherical structural groups, structural synthesis, mobility analysis.*

Introduction. Serial spherical manipulators are made an one base link and end effector link connected by the kinematic chains with three revolute joints with the axes intersecting in the center of sphere. The mobility of serial robotic system indicates the number of independent actuators. If mobility $M = 0$ of spherical kinematic chains we will get a simple spherical structural group of second class with $n = 2$ and $p_1 = 3$. By the same way we will get spherical structural groups $n = 4$, $p_1 = 6$ (third and fourth classes). Class of spherical structural groups describe the number of joints on platforms and by the number of joints on the closed loop.

In [1;2] the mobility number is characteristic of an independent loop $L = C - B$, where B number of platform and $C = C_l + C_b + C_{jb}$ is sum of legs, branches and joints between two platforms. Various analytical methods are used to calculate the mobility λ of manipulators using constraint screw theory [3]. The matrix notation was introduced in [4] represent mobility. Structural synthesis of same classes manipulators with configurable platform has been investigated in [5]. Recently, the analytical and numerical calculation of the mobility of over constraint manipulators with reconfigurable end-effectors has been done in [6].

Structural formulas for structural synthesis and analysis of robot manipulators. This section provides a unified frame framework for the calculation of the mobility and number of independent loops in a spherical serial manipulators of second, third and fourth classes. This results may be considered as known, but present framework provides the necessary background for the structural synthesis of complex serial manipulators.

A general serial spherical manipulator comprises by three moving link and one fixed leg. The motion of end-effector will displaced on the face of sphere. The three main types of 1-DoF joints are revolute joints with the directions intersecting in the senter of sphere, so

$$M = \sum_{i=1}^{j} f_i = 3 \quad \text{it means} \qquad (RRR)\text{—}\!\!< \tag{1}$$

where: j=3, brakes "(   )" – represents the intersection directions of kinematic pairs; "⫽⫽⫽" – fixed frame; —< - end effector.

As were showed in [2] the number of independent loops is equal:

$$L = j_b - B - C_b - C_{jb} \tag{2}$$

where:
B – the number of mobile platforms;
j_b - the total number of joints on the mobile platforms;
C_b - the total number of branches between mobile platforms;
C_{jb} - the total number of joints between mobile platforms.

The total number of joints on the mobile platforms can be also describe a

$$j = C_l + 2C_b + 2C_{jb} \tag{3}$$

where: C_l - the total number of legs.

Combining equations (2) and (3) we will get the total number of independent loops in the following form:

$$L = C - B \tag{4}$$

where:
$C = C_l + C_b + C_{jb}$ is the sum of numbers legs, branches and joints between platforms.

It is known that the position and orientation of the rigid body in space can be described by parameter $\{\lambda_k\}_1^6$. In the same time the general constraint for motion of the riged body in space can be described by parameter $\{d_k\}_0^5$. So, the general constraint for motion of rigid body in space can be written as follow:

$$\{\lambda_k\}_1^6 + \{d_k\}_0^5 = \lambda + d = 6 \tag{5}$$

It is known that the position and orientation of the couple "k" in each closed loop it is equal to the motion parameter λ_k of close loop, so for "k" structural group we will have

$$\sum_{i=1}^{j} f_i + \sum_{k=1}^{L} \lambda_k = 0 \tag{6}$$

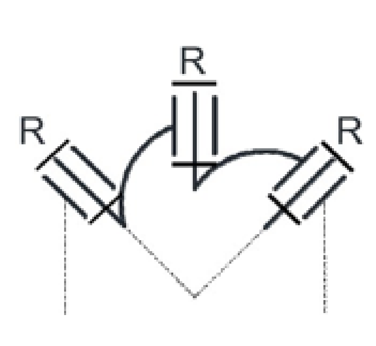
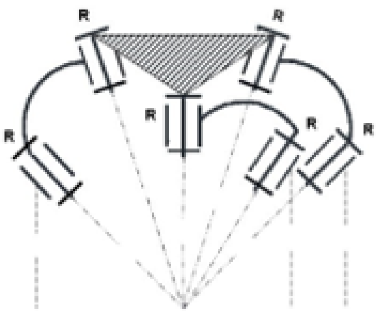
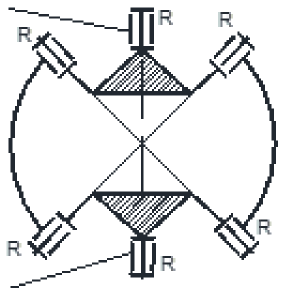
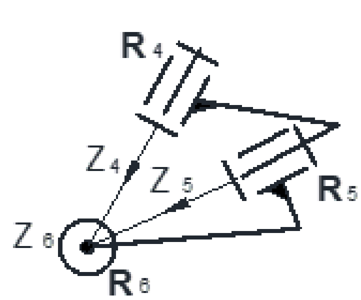
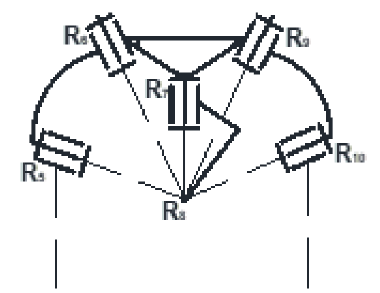
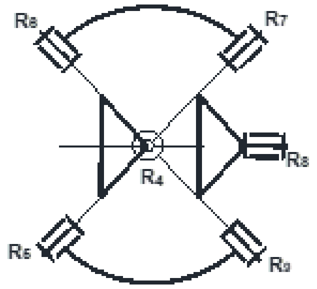
When the displacement variables in structural groups correspondence with DoF of joint in serial manipulators and combining equations (6) and (1) we will get the structural formula for the multiloops serial manipulators as follows:

$$M = \sum_{i=1}^{j} f_i - \lambda L \quad \text{or} \quad M = \sum_{i=1}^{j} f_i - (6 - d_k)L \tag{7}$$

The above equations (1), (6) and (7) show that basically the mobility number of serial multiloop manipulator is associated with the constraint of an independent loop.

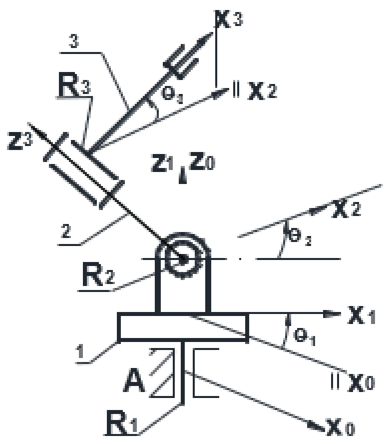
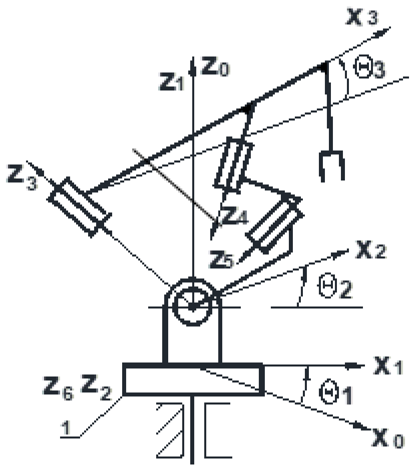
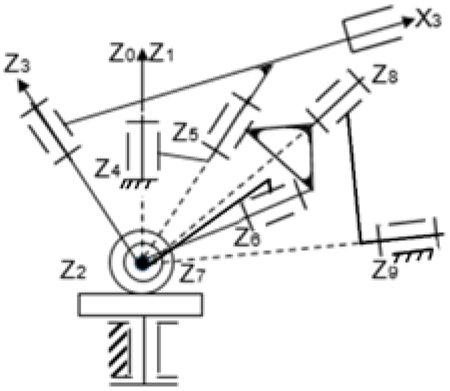
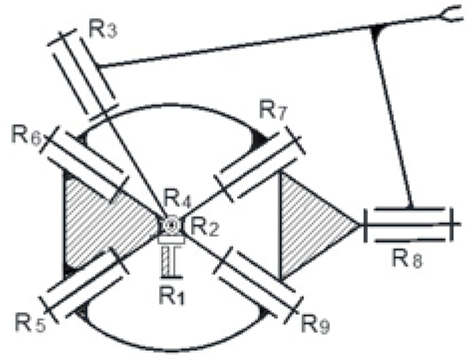
New serial spherical multiloop manipulators. The classic geometrical structural synthesis for the spherical groups with mobilities M=0 are illustrated in Table1. It is introduced the three structural spherical groups (RRR), $(R-RRR-R)$ and $((R<\begin{matrix}R & R\\ R & R\end{matrix}>R))$ from space $\lambda=3$ with numbers of independent loops $L(1,2,2)$, number of moving link $n(2,4,4)$, number of legs $c_l(2,3,2)$, number of branch $c_b(0,0,2)$ and number of platform $B(1,1,2)$ respectively.

Table 1. Kinematic chains of spherical structural groups

Second class of structural group	Third class of structural group	Fourth class of structural group
$M=0,\lambda=3,L=1,n=2$	$M=0,\lambda=3,L=2,n=4$	$M=0,\lambda=3,L=2,n=4$
		
1	2	3
$B=1,c_l=2,R=3,$ (RRR)	$B=1,c_l=3,R=6,$ $(R-R,R-R,R-R)$	$B=2,c_l=2$ $c_b=2,R=6$ $\begin{bmatrix} & R-R & \\ R & & R \\ & R-R & \end{bmatrix}$
		
4	5	6

So, the first two spherical structural groups are called second and third classes on the base of platform legs (Table 1(1, 2)), by the third spherical structural group is called fourth class on the base of links number of closed loop (Table 1(3)). The structural synthesis process is to design a new spherical serial manipulators with closed loops structures (Table 2). The process are transform the serial spherical (RRR) manipulator to the serial spherical multiloop manipulators by adding the spherical structural groups of second, third and fourth classes (Table 2).

Table 2. Structural syntesis of spherical manipulators

<table>
<tr><th>Structure of serial spherical manipulators</th><th>Structures of serial multiloop spherical manipulators</th></tr>
<tr><td>$M = 3, \lambda = 3, d = 3$</td><td>$M = 3, \lambda = 3, d = 3$; Second class</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>1</td><td>2</td></tr>
<tr><td>$M = 3, \lambda = 3, d = 3$; Third class</td><td>$M = 3, \lambda = 3, d = 3$; Fourth class</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>3</td><td>4</td></tr>
</table>

In order to construct a serial spherical multiloop manipulators should be consistent with the following conditions:

- Creating simple over constraint spherical structural groups.
- Class spherical structural groups are defined by the number of independent points on the moving platforms (two, three-Table 1.1 and 1.2) and by the number of moving links in the closed spherical loops (four-Table 1.3).
- Create new serial spherical multiloop manipulators by added spherical structural groups to the serial spherical manipulators.
- Computer-aided spherical structural synthesis.
- Generation of the branches and legs of spherical manipulators by describing the axes of kinematic pairs directed throw the center of sphere.

Conclusion Spherical structural synthesis is performed for serial spherical multiloop manipulators the structural groups of second, third and fourth classes. One of the fundamental area of the robotic science “Structural synthesis of robotic system” iz applied and developed for the serial spherical multiloop manipulators with general constraints three. A new procedure for structural synthesis of multiloop serial spherical manipulator are proposed.

Several spherical manipulators with general constraint three are given. Using this study any designer can developed the structural synthesis problem of serial spherical multiloop manipulators.

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