The problem of manipulation and angular orientation of gripping devices of construction robots

E V Marsova, S B Benevolenskiy, M Uu Abdulkhanova, V S Ershov and A.G Savelyev

Moscow Automobile and Road State Technical University (MADI), 64, Leningradsky Ave., Moscow, 125319, Russia

E-mail: dm@madi.ru

Abstract. The article describes the method of simple kinematic connections, which allows to organize at the matrix level the solution of problems of spherical trigonometry and angular orientation, which is reduced to the decomposition of the original matrix description of the problem into a system of simple matrices, the sequential solution of which individually or in combinations, allows to produce unambiguous results in the absence of restrictions in the original data. The mathematical apparatus of homogeneous transformations makes it possible to calculate the values of angular reversals in all intermediate joints, from the first to the n-1st, uniquely determining their required spatial orientation, as well as the spatial orientation of the end section of the switchgear.

A number of Russian and foreign research centers are working on the development of crane-manipulators with various types of bonds for the installation of building elements of buildings. Depending on the specific purpose, they use rigid, flexible and combined connections. Some constructions are equipped with a device for temporary support orienting body on the overlap of the working horizon in order to ensure the necessary positioning accuracy. A feature of these designs is the use of special load-gripping devices with several degrees of mobility, providing accurate orientation of the mounted elements. These devices provide correction of the angular positions of the mounted structure in two planes, a turnabout the vertical axis and its vertical implantation.

Figure 1. Perspective variant of the crane-manipulator for installation works
Consideration of the kinetic schemes of cranes allows us to assess their greatest potential for use in construction and installation operations, automation and robotization. Successful in this sense is the scheme with rotational kinematic pairs, presented in Figure 1.

The presence of rigid connections of links allows to minimize the positioning errors, freedom of maneuvering while installation of structural building elements.

The crane-manipulator has six local degrees of freedom, which ensures the movement of structural elements into the working area and fixing to a predetermined position. This method of positioning building structures is quite versatile and allows you to use it in the creation of capture devices of construction and installation of robotic systems that perform in addition to the standard functions of capture and stabilization in a given position of the installation elements, their orientation in three dimensions. Therefore, the problem of manipulation and angular orientation is reduced to solving the problems of spatial movement of capture devices. The efficiency of work functions is determined by the modularity of the hardware, software redundancy and the level of intellectual organization of the control system. The implementation of such functions requires the development of an analytical model that implements a universal set of operations for processing digital information provided by the sensor system. The principles of initial information processing incorporated in the model should ensure the independence of its structure and algorithmic support from structural modifications of the kinetic chain of capture devices.

Modeling of processes of trajectory movement and fixation in the space of the gripper device uses the results of the inverse kinematics problem, the solution of which gives a set of variable parameters in the nodes of the joint of the manipulation system in the form of a matrix.

Used in practice scalar analytical and search methods for solving such a kinetic problem are not effective enough because of the loss of accuracy of reproduction of the trajectory of the capture devices when converting the matrix of the initial kinetic relations. The proposed method of simplest kinetic bonds is devoid of this drawback.

Any problem of angular orientation of coordinate systems (CS) with a common origin is described by the matrix relation:

\[ \prod_{i=1}^{\mathfrak{m}} R_l(\alpha_i) = I, \]  

(1)

\( I \) – unit diagonal matrix; \( R_l(\alpha_i) \) – matrix of angular rotations of CS around one of its axes.

Then the \( \alpha_i \) angle of the axes \( Z \ Y \ X \) respectively will have the form:

\[
R_1(\alpha_i) = \begin{bmatrix}
\cos \alpha_i & -\sin \alpha_i & 0 \\
\sin \alpha_i & \cos \alpha_i & 0 \\
0 & 0 & 1
\end{bmatrix},
\]  

(2)

\[
R_2(\alpha_i) = \begin{bmatrix}
\cos \alpha_i & 0 & \sin \alpha_i \\
0 & 1 & 0 \\
-\sin \alpha_i & 0 & \cos \alpha_i
\end{bmatrix},
\]  

(3)

\[
R_3(\alpha_i) = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \alpha_i & -\sin \alpha_i \\
0 & \sin \alpha_i & \cos \alpha_i
\end{bmatrix}.
\]  

(4)

The ratios (1) show that there is a sequence of individual rotations of the CS, by which it is possible to realize the angular rotations of an arbitrary state of the Cartesian CS to its initial position.

The ratios (1) capture a kinematic connection in the tasks of the angular orientation and at the smallest number (five) factors you can obtain the simplest kinematic connection in the form of simple matrices angular rotations of the components with the following main properties.
1. The matrix $R_l(\alpha)$ is orthogonal, if for any $l = 1, 2, 3$ the relation is valid:

$$R_l^{-1}(\alpha) = R_l^T(\alpha),$$

(5)

$(-^1), (T)$ are the degrees of inverse and transpose matrices.

2. A series of successive rotations of the CS relative to any of the axes does not complicate the transformation matrix of angular coordinates:

$$\prod_{i=1}^{n} R_l(\alpha_i) = R_l\left(\sum_{i=1}^{n} \alpha_i\right),$$

(6)

$n$ is any number.

3. Transposed matrix of elementary angular rotation around one of the axes in the forward direction is adequate to the matrix of the same rotation in the reverse direction:

$$R_l^T(\alpha) = R_l(-\alpha).$$

(7)

So if: $\alpha = \pm \pi$, then:

$$R_l(\pm \pi) = R_l^T(\pm \pi).$$

(8)

Rotation around one of the axes of the CS can be adequately replaced by the same magnitude and opposite direction of the rotation angle around the axis, replacing its direction to the opposite.

The formulas of such transformation of coordinates are given in table 1

| Table 1. Euler Matrix Transposition Formulas |
|---------------------------------------------|
| $R_l(\pi)R_2(\alpha)R_l^T(\pi) = R_l^T(\alpha)$ | $R_l(\pi)R_1(\alpha)R_l^T(\pi) = R_l^T(\alpha)$ |
| $R_l^T(\pi)R_3(\alpha)R_l^T(\pi) = R_l^T(\alpha)$ | $R_l^T(\pi)R_2(\alpha)R_l^T(\pi) = R_l^T(\alpha)$ |

4. The property of degeneracy matrices of simple angular rotations: matrix of simple angular rotations equal to each other in the absence of rotations around the respective axes of rotation, that is:

$$R_l^T(\alpha)\bigg|_{\alpha=0} = R_l(\beta)\bigg|_{\beta=0} = R_l(\gamma)\bigg|_{\gamma=0} = I.$$  

(9)

5. Any angular rotation of the Cartesian coordinate system can be reduced to the replacement of the notation of its axes.

Since there are only two variants of the simplest angular rotations of the original coordinate system associated with the replacement of the designation of its axes, it turns out only six possible modifications of such transformations recorded in table 2, which boil down to two additional turns to the corner $\pi / 2$.

| Table 2. Types of modifications |
|--------------------------------|
| Direct transformations | Reverse transformations |
| $R_3(\pi / 2)R_1(\alpha)R_3^T(\pi / 2) = R_2(\alpha)$ | $R_3(\pi / 2)R_1(\alpha)R_3^T(\pi / 2) = R_l^T(\alpha)$ |
| $R_1(\pi / 2)R_2(\alpha)R_1^T(\pi / 2) = R_3(\alpha)$ | $R_1(\pi / 2)R_2(\alpha)R_1^T(\pi / 2) = R_l^T(\alpha)$ |
| $R_2(\pi / 2)R_3(\alpha)R_2^T(\pi / 2) = R_1(\alpha)$ | $R_2(\pi / 2)R_3(\alpha)R_2^T(\pi / 2) = R_l^T(\alpha)$ |
The simplest kinematic bond (SKB) is a sequence of angular transformations with the number of rotations of the axes equal to five.

There are only three distinct types of SKB, which are shown in Figure. 2. These sequences of axis rotations will be the simplest, displaying expressions with the least number of matrices to be multiplied.

Given the direction of successive transformations, rotations of the axes, we obtain matrix relations for all groups of SKB with rotations:

A. At the angles b, d, e, c, a:

\[
R_1(b)R_2(d)R_3(e)R_4(c)R_5(a); \quad (10)
\]

B. At the angles a, m, l, p, n:

\[
R_1(a)R_2(m)R_3(l)R_4(p)R_5(n); \quad (11)
\]

C. At the angles f, b, g, k, h:

\[
R_1(f)R_2(b)R_3(g)R_4(k)R_5(h); \quad (12)
\]

Further simplifications of at least one of the matrix relations (10 – 12), zeroing any of the angular coordinates, will cause the zeroing of the remaining angles.

**Figure 2. Geometry of the simplest kinematic bonds**

It can be stated that the method of the simplest kinematic connections allows to organize at the matrix level the solution of a wide range of problems of spherical trigonometry and angular
orientation. The basic principle of the solution is the decomposition of the original matrix description of the problem into a system of elementary ones, the sequential solution of which individually or in combinations (depending on convenience), allows to produce unambiguous results in the absence of restrictions in the original data. The mathematical apparatus of homogeneous transformations makes it possible to calculate the values of angular reversals in all intermediate joints, starting from the first and ending with the n-1st, uniquely determining their required spatial orientation, as well as the spatial orientation of the end section of the RS.

References

[1] Bataev S B, Vorobyov V A, Degtyarev V and Mazhibayev O M 1996 Methods and means of automation of road construction works and machines (Almaty: Gylym) p 262

[2] Bulgakov A G, Gerner I and Kaden R 1990 Studies and practical examples of the organization of production and use of robots in the construction industry (Machines, mechanisms, equipment and tools M VNIINTPI vol 1) p 48

[3] Bulgakov A G, Gerner I and Kaden R 1991 Microprocessors in automation systems of construction equipment (Technology of construction and installation works M VNIINTPI vol 3) p 52

[4] Bulgakov A G and Sukhomlinov A D 1989 Application of laser information-measuring systems in construction. (Technology of construction and installation works M VNIIESM vol 3) p 53

[5] Bulgakov A G and Schindler I 1994 Means and systems of automation in construction machinery. Technology and automation of construction. (M VNIINTPI vol 4) 56 p