MATHEMATICAL MODELING OF THE WALKING HEXAPOD ROBOT USING DENAVIT- HARTENBERG PARAMETERS

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ABSTRACT: *This paper presents a kinematic model of a walking hexapod robot. The kinematic model is described using the Denavit-Hartenberg parameters and is performed on the one leg of the hexapod robot with the assumption that all legs are identical. The direct kinematics is made for an open kinematic chain but also for a closed kinematic chain.*

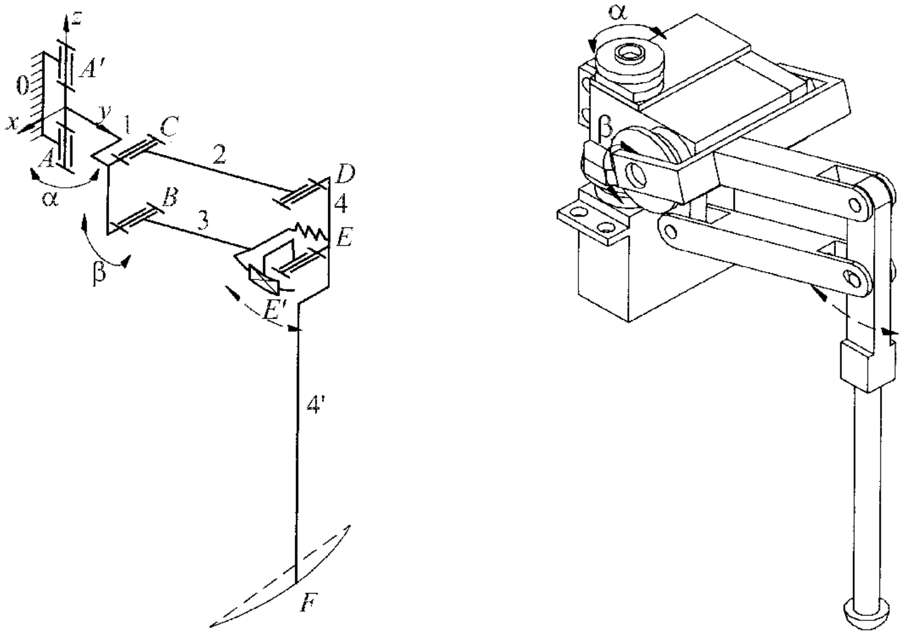
KEY WORDS: stability of robot, hexapod robot, Denavit-Hartenberg parameters

1. INTRODUCTION

A hexapod robot is a mechanical and electronic device whose movement is based on the six legs. Unlike other types of robots, with two, three or four legs, the hexapod robot has superior flexibility and stability [1]. Therefore, the behavior of a hexapod robot is much more complex, especially due to the fact that not all six legs are necessary for movement; the others can be used to lift objects or to better target the robot to certain areas [2, 3]. An analysis of several types of gait as well as the kinematics of a hexapod robot is detailed in [4, 5].

2. THE STRUCTURE OF A LEG

Given that, if the robot has to make a move after a rectilinear trajectory (forward or backward), the trajectory of the extremity of the foot in the support phase must also be linear. If the foot has only rotating kinematic torques in its structure, this presupposes that the foot has at least three active torques (conductors), ie at least three drive motors. One motor ensures the raising-lowering of the foot, the second ensures the advancing-retraction of the foot (by rotating it around a vertical axis), and the third corrects the deviation from rectilinearity of the trajectory of the extremity of the foot in the support phase. For budgetary reasons (costs too high, three motors for one leg meaning 18 motors for the entire robot), but also for the simplification of the control algorithm, we opted for a leg structure with two active kinematic couplings, A and B (Fig. 1 a). But, in this situation, the trajectory of the extremity of the foot will be an arc of a circle (the trajectory drawn with a continuous line in Fig. 1 b). To eliminate this shortcoming, a passive kinematic coupling (E ') was introduced, "actuated" by a compression spring. Thus, in the support phase, the trajectory of the extremity of the foot will be corrected, this being the one drawn with an interrupted line.



(a) *(b)*

Fig. 1 Leg: a) structure; b) CAD 3D model

In order to ensure a better rigidity of the foot, a closed loop mechanism, of parallelogram type, was chosen. This mechanism also has the advantage that the EF element is permanently perpendicular to the ground surface.

The CAD model of the foot, using the structure described above, is shown in Fig. 1.b.

3. THE KINEMATIC MODEL OF A LEG

The Denavit-Hartenberg convention will be used to write the kinematic model. Because the mechanism in the structure of a leg is not an open kinematic chain, but contains a closed loop, this complicates things a bit.

3.1. DIRECT KINEMATICS

The problem of direct kinematics assumes that the kinematic parameters of the conducting torques are known and it is required to determine the position and orientation of the extremity of the foot. To solve the direct kinematics, the Denavit-Hartenberg parameters will be used

3.2. DENAVIT-HARTENBERG CONVENTION

We consider, for the beginning, an open kinematic chain, the scheme of the coordinate transformations performed in order to perform the direct kinematics being presented in Fig. 2.

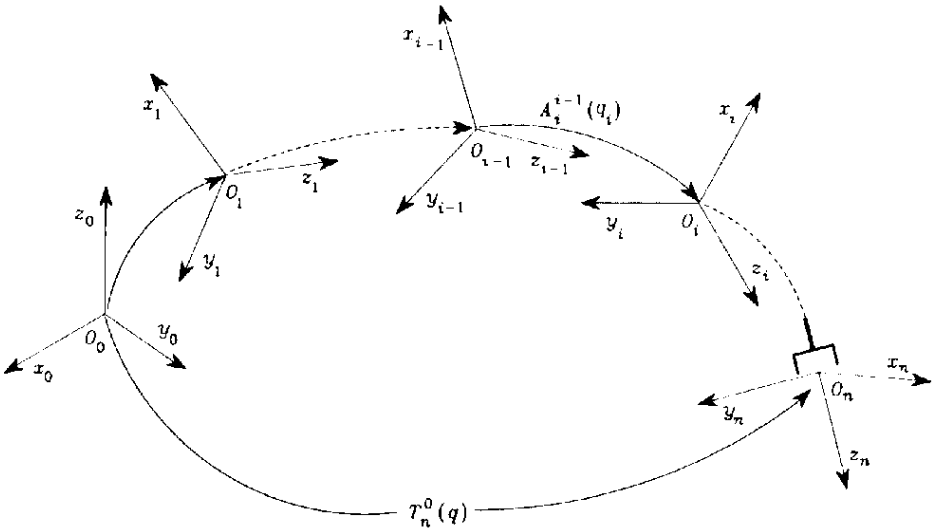


Fig. 2. Transformations of coordinates in an open kinematic chain

To solve the direct kinematics, a triorthogonal coordinate system is attached to each element and then the matrices that define the coordinate transformations are written, at the transition from one coordinate system to the next. Finally, write the total homogeneous transformation matrix, using the relation:

$$ {}^0_nT = {}^0_1A \cdot {}^1_2A \cdot \ldots\ldots\ldots \cdot {}^{n-1}_{n}A \qquad (1) $$

Attaching the axle systems can be done arbitrarily, but it is more convenient to follow certain rules, in our case the rules imposed by the aforementioned convention.

We consider two elements i-1 and i, connected by the kinematic coupling i (Fig. 3). The Denavit-Hartenberg Convention will be used to attach the coordinate system and, as follows:

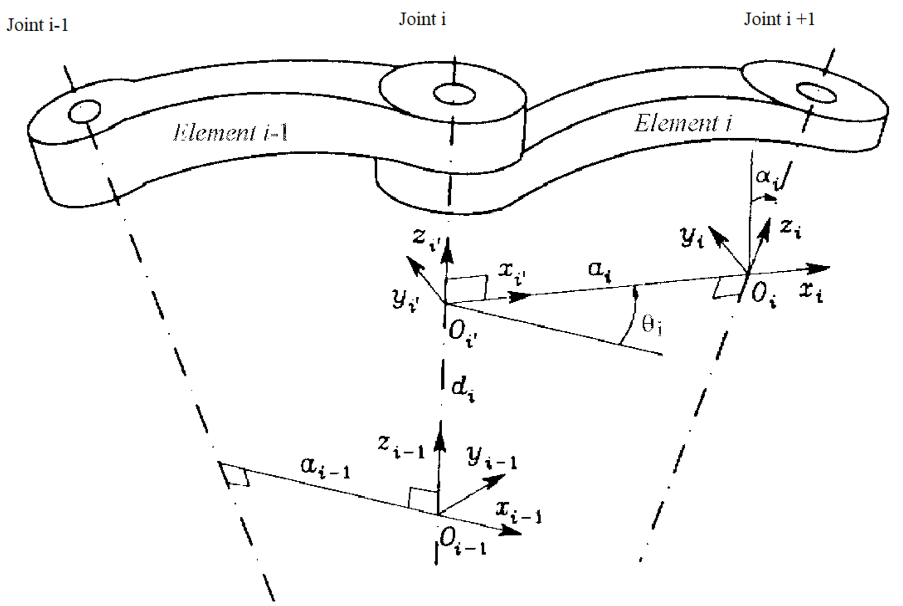


Fig. 3. Denavit-Hartenberg parameters

- The z_i - axis coincides with the i + 1 kinematic coupling axis.
- The O_i origin of the system will be at the intersection of the z_i axis with the common perpendicular to the z_{i-1} and z_i axes. Also, the origin of O_i is at the intersection of the common normal with the z_{i-1} axis.
- Axis x_i is along the perpendicular to the axes z_{i-1} and z_i, having the direction from the coupling i to the coupling i + 1.
- The y_i axis results so that the coordinate system respects the rule of the right hand.

The Denavit-Hartenberg Convention offers several solutions in the following cases:

- For the initial system {0}, only the z_0 axis is specified. The origin O_0 and the x_0 axis can be chosen arbitrarily. The x_0 axis is chosen, however, so that the transformation of coordinates when switching from system {0} to system {1} is as simple as possible.
- For the n system, because there is no kinematic coupling n + 1, the z_n axis is not defined uniquely, because the x_n axis must be perpendicular to the z_{i-1} axis. Usually, the coupling n is rotating, so the z_n axis will be collinear with the z_{i-1} axis.
- When two consecutive axes are parallel, their common perpendicular is not uniquely defined.
- When two consecutive axes intersect, the direction of the x_i axis is arbitrary.
- When the coupling is translational, the direction of the z_{i-1} axis is arbitrary.

In such cases, the attachment of the axis systems is done in such a way as to make the problem as simple as possible; for example, the axes of two consecutive systems may be parallel.

Once the coordinate systems have been established, the position and orientation of the system i in relation to the system i-1 are completely defined by the following parameters: a_i - the distance between z_{i-1} and z_i, measured along x_i; d_i - distance between x_{i-1} and x_i, measured during z_{i-1}; α_i - the angle between the axes z_{i-1} and z_i, measured around the axis x_i; it is positive when the rotation is done in trigonometric direction; θ_i - the angle between the axes x_{i-1} and x_i, measured around the axis z_{i-1}; this is positive when the rotation takes place in a trigonometric direction.

Two of these parameters (d_i and α_i) are constant and depend only on the geometry of the robot. Of the other two parameters, only one is variable, depending on the type of kinematic coupling:

- *Θ_i is variable if the coupling is rotating;*
- *d_i is variable if the coupling i is translational.*

The transition from the reference system i-1 to the system i' takes place by a transition with d_i along the axis z_{i-1}, followed by a rotation with Θ_i around the axis z_{i-1}:

$$ {}^{i-1}_{i'}A = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & 0 \\ \sin\theta_i & \cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

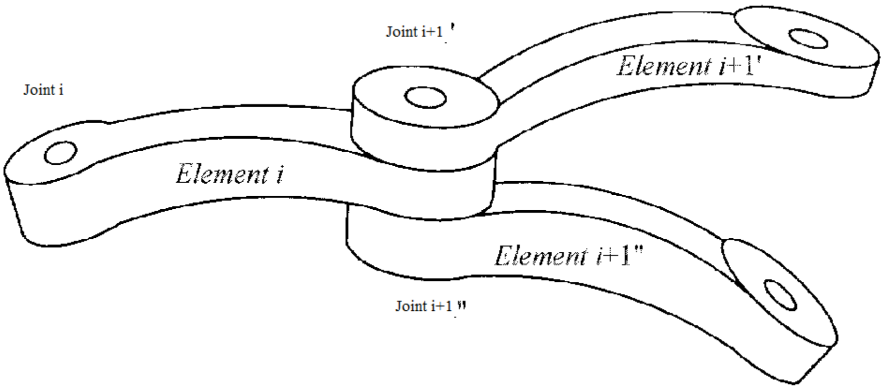
The transition from system i' to system i takes place by a translation with a_i along the axis $x_{i'}$ and a rotation around $x_{i'}$ with angle α_i ; the corresponding homogeneous matrix is:

$$ {}^{i'}_{i}A = \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & \cos\alpha_i & -\sin\alpha_i & 0 \\ 0 & \sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

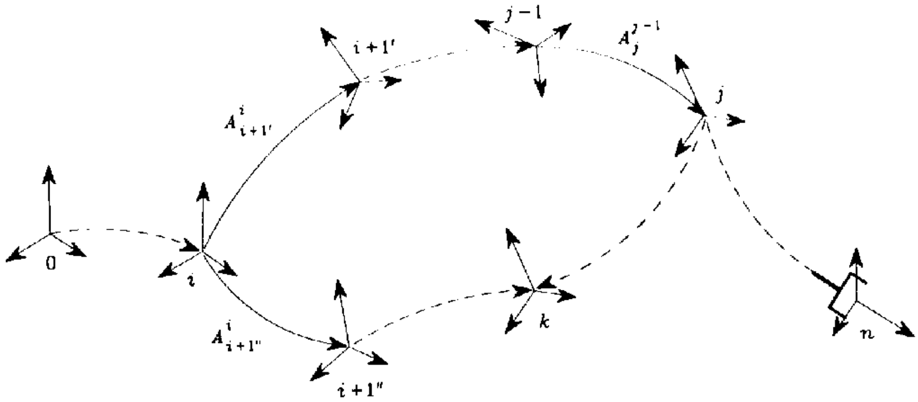
The total homogeneous matrix, at the transition from system i-1 to i will be:

$$ {}^{i-1}_{i}A = {}^{i-1}_{i'}A \cdot {}^{i'}_{i}A = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

In the case of a closed kinematic chain, the number of kinematic couplings c is greater than the number of moving elements n. The number of closed loops is equal to the difference c-n.



(a)



(b)

Fig. 4. Closed kinematic chain: a) the connection between the elements; b) transformations of coordinates.

As seen in figure 4.a, in this situation some elements are connected to more than one element. To solve the problem and determine the kinematic parameters, proceed as follows:

- A passive kinematic coupling is chosen and this coupling is loosened, obtaining an open kinematic chain, in the branched structure;
- Calculate the homogeneous transformation matrix, according to the Denavit-Hartenberg convention;

• The relations between the parameters of the coordinate systems having the origins in the cut kinematic torque are sought;

• Determine the constraints for a small number of variables;

• The total homogeneous transformation matrix is expressed by composing the elementary transformation matrices.

4. CONCLUSIONS

Direct kinematic problem - refers to the determination of position and orientation (noted briefly - configuration) to a reference landmark for the robot effector at a certain time, when the relative kinematic attitudes of all segments of the kinematic chain that makes up the robot are known, at that time. In other words, it means that the kinematic configuration of the segment 1 with respect to the segment 0, given by the position of the joint 1, of the segment 2 with respect to the segment 1, given by the position of the joint 2, etc. is known at that time.

The Denavit - Hartenberg method is the most widespread method of geometric modeling of robots has the advantage of the small number of parameters required to move from one reference system to another

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