THE GEOMETRICAL ANALYSIS OF A TETRAPOD BIO-MECHANISM USING SOLIDWORKS AND COSMOSMOTION

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Abstract: The paper analyzes in terms of a geometric point of view a kind of bio-mechanism consisting of a legs of a tetrapod animal. Each front leg is a complex structure with three closed contours and each rear leg has only two closed contours. In this paper it was analyzed the geometry of bio-mechanism of a rear leg, both by calculation in Mathcad (based on vector equations) and by modeling and measuring in SolidWorks. At last it was built the soil contact point trajectory.

Keywords: bio-mechanism, tetrapod, geometrical analysis, simulation

1. INTRODUCTION

Through the physical modeling of a dog, one obtains a bio-mechanism (mobile bio-robot), in which the legs are made like flat articulated kinematic chains. Each foot physical modeled is driven by a DC electric motor, powered by an accumulator battery. The dog body is physical shaped from two pieces, front and rear hinged together. Also, the dog head is connected to the body, by articulation at the neck. Stated that, in the case of this physical model the base of rear feet has a rotating in vertical plane [1].

2. KINEMATIC SCHEME AND THE MOBILITY OF BIO-MECHANISM

In the frontal plane, physical model of dog (Figure 1) shows two complex articulated kinematic chains for front and rear feet.

![Dog's Physical model](image)

The kinematic scheme of the tetrapod bio-mechanism is carried out in longitudinal vertical planes that are the linkages of the two legs, the back (Figure 2a) and front (Figure 2b). Both mechanisms are articulated in a top horizontal bar, which is physically molded dog body.

A₀ and B₀ joints of each mechanism to the upper deck furniture (Figure 2) are considered as the basic link, which is why this platform was marked with 0.

![Kinematic scheme of plane legs articulated mechanisms](image)

Each of the two mechanisms (back and front) has a first quadrilateral $A₀ABB₀$, kinematic chain, which consists of kinematic elements 0, 1, 2 and 3. The second contour of each kinematic mechanism is the articulated quadrilateral $ACED$ consisting of cinematic elements 1, 2, 4 and 5 (Figure 2a) or $BCED$, consisting of items 2, 3, 4 and 5 (Figure 2b). The front leg mechanism includes a third kinematic contour $DGHF$ (Figure 2b), which consists of cinematic elements 2, 5, 6 and 7.

The purpose of this work is the geometric analysis of the first rear leg kinematic chain mechanism (Figure 2a - $A₀ABB₀$ chain) and plotting the point trajectory of contact with soil.

In the paper is solved, using Mathcad software, the system of equations characterizing by the geometry and kinematic chain and is graphical represented adding with SolidWorks software the position of kinematic chain.

One realizes the kinematic scheme of a tetrapod mechanism with SolidWorks software. The mechanism elements that form those two kinematic chains (Figure 3) have the following dimensions and relationships between them:
A_{0}B_{0}=12\text{mm}; \quad yB_{0}=2\text{mm}; \quad A_{0}A=28\text{mm}; \quad AB=13\text{mm}; \quad B_{0}B=30\text{mm}; \quad A_{0}C_{1}=15\text{mm}; \quad CC_{1}=2.5\text{mm}; \quad AD_{1}=31\text{mm}; \quad DD_{1}=4\text{mm}; \quad CE=40\text{mm}; \quad DE=23\text{mm}; \quad DM=66\text{mm}; \quad DF_{1}=54\text{mm}; \quad FF_{1}=25\text{mm}; \quad CC_{1} \perp A_{0}A; \quad DD_{1} \perp AB; \quad FF_{1} \perp DM, \quad \phi_{1}=100^0.

In SolidWorks it is realized and presented in Figure 5, the kinematic scheme from Figure 4, for the angle as \phi_{1}=100^0.

3. KINEMATIC MODELING OF THE FIRST KINEMATIC CHAIN OF THE REAR LEG

A_{0} and B_{0} joints of the mechanism on the upper mobile deck are regarded as links in the frame, which is why this platform was marked with 0. The mechanism consists of two kinematic chains, A_{0}ABB_{0} and ACDE.

In SolidWorks it is realized and presented in Figure 5, the kinematic scheme from Figure 4, for the angle as \phi_{1}=100^0.

Plane mechanism has two independent contours. It choose a Cartesian coordinate system with origin fixed in the joint A_{0}, with axes A_{0}x and A_{0}y oriented as in Figure 4).

Fig.3. The plane Articulated mechanism of rear leg modeled in SolidWorks

To each side of the two independent closed contours, convenient way to choose, such as position angles (measured counterclockwise) to be as small (Figure 4).

Fig. 5. The first kinematic chain of the rear leg, modeled in SolidWorks

Grouping the terms from equation above so that the left side to be vectors containing the unknown (angle \phi_3 and angle \phi_2) and the right to be known as the size and direction vectors (angle \phi_1 is an independent parameter, being considered in a given period).

One have next notation: B_{0}A_{0}=l_{0}, \quad A_{0}A=l_{1}, \quad BA=l_{2}, \quad B_{0}B=l_{3}, \quad for that the vectorial equation it is written like this:

\begin{align}
\vec{l}_2 + \vec{l}_3 &= \vec{l}_1 + \vec{l}_0
\end{align}

Designing the vectorial perimeter on coordinate axes A_{0}x and A_{0}y, one obtains the following scalar equations:

The system of nonlinear equations can be solved by eliminating one row of two unknowns \phi_3 and \phi_2. For
this, the system is written more compact, using the
follow notations:

\[ A_0A_1 = \sqrt{A_0B_0^2 - Y_0^2} \]

(5)

\[ \phi_0 = \sin \left( \frac{Y_0}{A_0A_1} \right) \]

(6)

To find the angle \( \phi_2 \), it isolated the terms which contains
unknown \( \phi_2 \), it multiply and adding those two equations.
The obtained expression is a trigonometric with variable
coefficient like bellow:

\[ \phi_2 = \frac{A_0A_1}{A_0B_1} \]

(7)

The variable coefficients:

\[ A_2(\phi_1) = 2l_2b_2(\phi_1); \quad B_2(\phi_1) = 2l_2b_1(\phi_1); \]

\[ C_2(\phi_1) = l_2^2 - l_2^2 - b_1^2(\phi_1) - b_2^2(\phi_1) \]

(8)

The equations solutions are:

\[ \phi_2 = \frac{A_0A_1}{A_0B_1} \]

(9)

\[ \phi_2 = \frac{A_0A_1}{A_0B_1} \]

(10)

where the variable coefficients for \( \phi_3 \) have the expressions:

\[ A_3(\phi_1) = 2l_3b_2(\phi_1); \quad B_3(\phi_1) = 2l_3b_1(\phi_1); \]

\[ C_3(\phi_1) = l_2^2 - l_2^2 - b_1^2(\phi_1) - b_2^2(\phi_1) \]

(11)

The coordinates of D point it calculates:

\[ x_D = x_A + AD \cdot \cos(\phi_2 + \alpha_2) = l_1 \cos \phi_1 + + l_2 \sin(\phi_2 + \alpha_2) \]

(12)

\[ y_D = y_A + AD \cdot \sin(\phi_2 + \alpha_2) = l_1 \sin \phi_1 + + l_2 \sin(\phi_2 + \alpha_2) \]

(13)

To determine the angle \( \phi_0 \) (Figure 4) will calculate the
length of \( \overline{A_0A_1} \) (Figure 5) in the triangle formed by
points \( A_0, B_0, A_1 \) (\( A_1 = 900 \) angle measure). Angle \( \phi_1 \) is
randomly selected for a position considered optimal.

A. The geometric analysis of kinematic chain in
MathCad and the obtaining the coordinates of D
point.

The following calculations are performed in Mathcad: \( \phi_0 \)
calculated angle triangle \( A_0B_0A_1 \), variable coefficients
and angles \( \phi_2 \) and \( \phi_3 \).

\[ A0A1 = \sqrt{A0B0^2 - Y0^2} \]

(14)

\[ \phi_0 = \sin \left( \frac{Y0}{A0A1} \right) \]

\[ b1 = B1 \cdot \cos(\phi1) \]

\[ b2 = B1 \cdot \sin(\phi1) \]

(15)

\[ A1 = 2 \cdot B2 \]

\[ B1 = 2 \cdot B1 \]

\[ C1 = B1^2 - C1^2 - b1^2 - b2^2 \]

(16)

\[ A2 = 2 \cdot B2 \]

\[ B2 = B1 \]

\[ C2 = B2^2 - C2^2 - b1^2 - b2^2 \]

It notes in Mathcad with \( \phi_{31} \) and \( \phi_{32} \) the two solutions
obtained for angle \( \phi_3 \). It notes in Mathcad with \( \phi_{31} \) and
\( \phi_{32} \) the two solutions obtained for \( \phi_3 \) angle.

\[ \Phi21 = 2 \arctan \left( \frac{A1 + \sqrt{A1^2 + B1^2 - C1^2}}{B1 - C1} \right) \]

\[ \Phi21 = 152.588 \quad \text{deg} \]

\[ \Phi22 = 2 \arctan \left( \frac{A1 - \sqrt{A1^2 + B1^2 - C1^2}}{B1 - C1} \right) \]

\[ \Phi22 = 0.953 \quad \text{deg} \]

\[ \Phi31 = 2 \arctan \left( \frac{A2 + \sqrt{A2^2 + B2^2 - C2^2}}{B2 - C2} \right) \]

\[ \Phi31 = 101.601 \quad \text{deg} \]

\[ \Phi32 = 2 \arctan \left( \frac{A2 - \sqrt{A2^2 + B2^2 - C2^2}}{B2 - C2} \right) \]

\[ \Phi32 = 51.918 \quad \text{deg} \]

(17)

From condition like \( \phi_2 \) and \( \phi_3 \) being sharp angles, result
that must keep only solutions \( \phi_{21} = 0.951^\circ \) and
\( \phi_{31} = 51.918^\circ \).

\[ xD1 = B1 \cdot \cos(\phi1) + l_1 \cdot \cos(\phi22 + \alpha_2) \]

\[ yD1 = B1 \cdot \sin(\phi1) + l_1 \cdot \sin(\phi22 + \alpha_2) \]

\[ xD2 = 2 \cdot B1 \cdot \sin(\phi1) + l_2 \cdot \cos(\phi22 + \alpha_2) \]

\[ yD2 = 2 \cdot B1 \cdot \sin(\phi1) + l_2 \cdot \sin(\phi22 + \alpha_2) \]

(18)

B. Obtaining the D point coordinates graphically,
using SolidWorks

Figure 3 is a kinematic chain in the SolidWorks design,
given the length and angle elements \( \phi_1 = 100^\circ \). With
SmartDimension command it determines and obtains the
coordinates of D point: \( x_D = 26.0772 \) mm \( y_D = 32.0196 \) mm (Figure 6).

![Fig. 6. The coordinates of D point display in SolidWorks](image)

4. THE SIMULATION OF REAR LEG MOVEMENT IN COSMOSMOTION DEVELOPED UNDER SOLIDWORKS

Using CosmosMotion developed under SolidWorks it build the soil contact of the point trajectory (Figure 7).

![Fig. 7. The point contact soil trajectory, realized in CosmosMotion](image)

The graph coordinate point of contact with the ground, function time is shown in Figure 8.

![Fig. 8. The graphic of the point contact soil coordinates](image)

5. CONCLUSIONS

The D point coordinate values obtained by calculation in Mathcad are very close to values measured by graphical way using SolidWorks, the difference between them being only a few tenths of mm, which is due to the number of decimal places to which the two programs work in showing results, respectively allowance. The mathematical calculus software and advanced modeling and analysis of three-dimensional motion review enabling an efficient analysis with correct and accurate results.

REFERENCES


