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

Alexis Negrea*, Viviana Filip Paul Ciprian Patic*****
*) Teaching Assistant Valahia University of Targoviste, E-mail: alexis_negrea@yahoo.com
**) Professor Valahia University of Targoviste, E-mail: v_filip@yahoo.com
***) Associate Professor Valahia University of Targoviste, E-mail: patic@valahia.ro

Abstract: *The paper analyzes in terms of a geometric point of view a kind of bio-mechanism consisting of a legs of a tetra pod 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, tetra pod, 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.

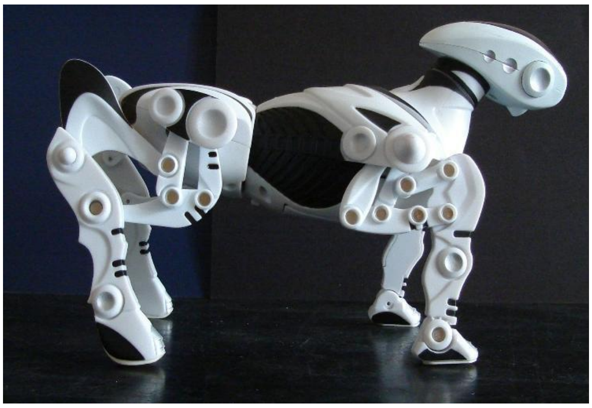
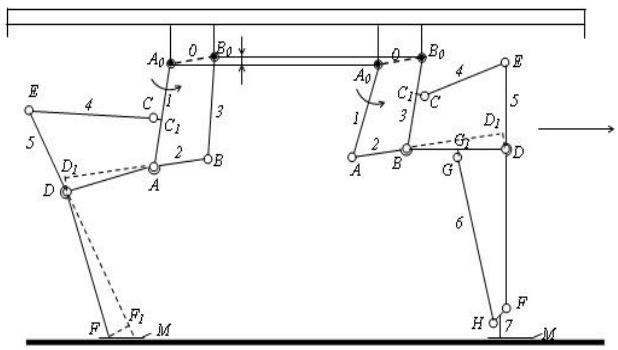


Fig.1. Dog's Physical model

The kinematic scheme of the tetra pod 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. A_0 and B_0 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.



a b

Fig. 2. Kinematic scheme of plane legs articulated mechanisms

Each of the two mechanisms (back and front) has a first quadrilateral A_0ABB_0 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 - A_0ABB_0 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 tetra pod mechanism with SolidWorks software. The mechanism elements that form those two kinematic chains (Figure 3) have the following dimensions and relationships between them:

A_0B_0=12mm; yB_0=2mm; A_0A=28mm; AB=13mm; B_0B=30mm; A_0C1=15mm; CC_1=2,5mm; AD_1=31mm; DD_1=4mm; CE=40mm; DE=23mm; DM=66mm; DF_1=54mm; FF_1=25mm; $CC_1 \perp A_0A$; $DD_1 \perp AB$; $FF_1 \perp DM$, $\varphi_1=100^0$.

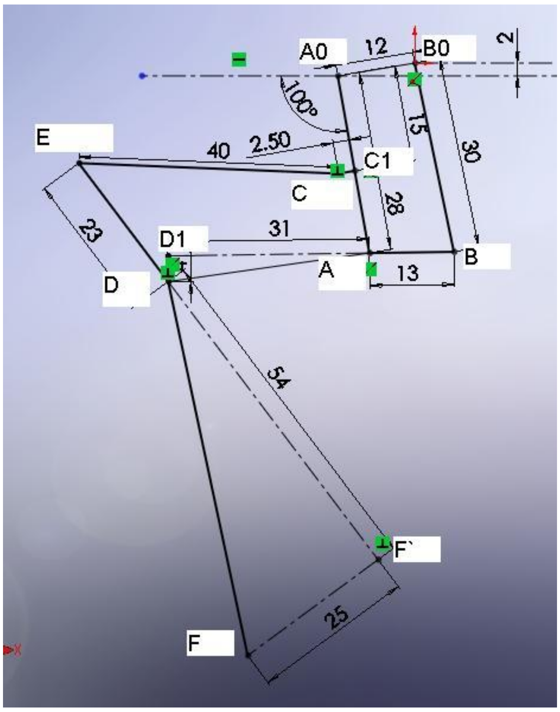


Fig.3. The plane Articulated mechanism of rear leg modeled in SolidWorks

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_0ABB_0 and ACDE.

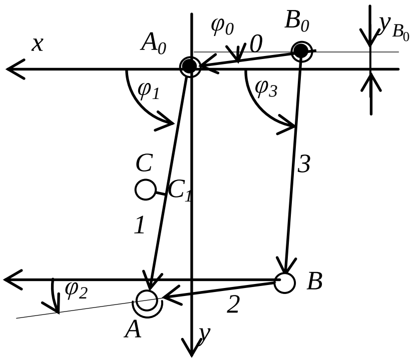


Fig.4. The first Kinematic chain of the rear leg

Plane mechanism has two independent contours. It choose a Cartesian coordinate system with origin fixed in the joint A_0, with axes A_0x and A_0y oriented as in Figure 4).

In SolidWorks it is realized and presented in Figure 5, the kinematic scheme from Figure 4, for the angle as $\varphi_1=100^0$.

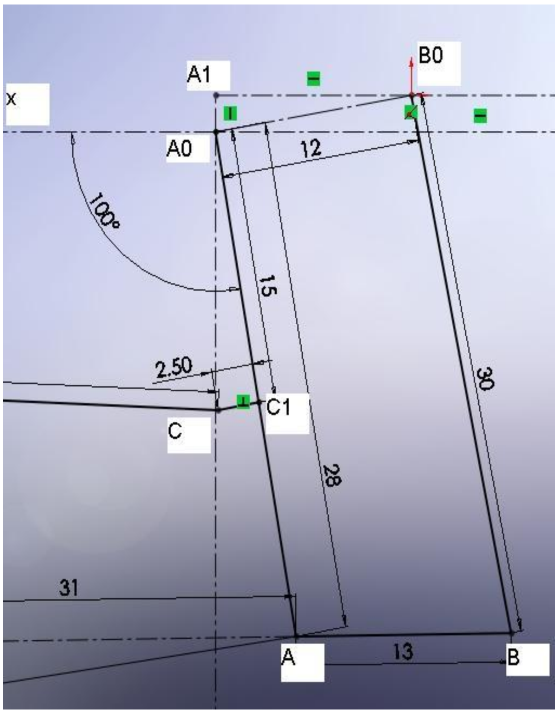


Fig. 5. The first kinematic chain of the rear leg, modeled in SolidWorks

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).

$$\overrightarrow{B_0A_0}+\overrightarrow{A_0A}=\overrightarrow{B_0B}+\overrightarrow{BA} \tag{1}$$

Grouping the terms from equation above so that the left side to be vectors containing the unknown (angle φ3 and angle φ2) and the right to be known as the size and direction vectors (angle φ1 is an independent parameter, being considered in a given period).

$$\overrightarrow{BA}+\overrightarrow{B_0B}=\overrightarrow{B_0A_0}+\overrightarrow{A_0A} \tag{2}$$

One have next notation: $B_0A_0=l_0$, $A_0A=l_1$, $BA=l_2$, $B_0B=l_3$, for the vectorial equation it is written like this:

$$\vec{l}_2+\vec{l}_3=\vec{l}_0+\vec{l}_1 \tag{3}$$

Designing the vectorial perimeter on coordinate axes A_0x and A_0y, one obtains the following scalar equations:

$$\begin{cases} l_2\cos\varphi_2+l_3\cos\varphi_3=l_0\cos\varphi_0+l_1\cos\varphi_1 \\ l_2\sin\varphi_2+l_3\sin\varphi_3=l_0\sin\varphi_0+l_1\sin\varphi_1 \end{cases} \tag{4}$$

The system of nonlinear equations can be solved by eliminating one row of two unknowns φ3 and φ2. For this, the system is written more compact, using the follow notations:

$$b_1(\varphi_1) = l_0\cos\varphi_0 + l_1\cos\varphi_1 \qquad (5)$$

$$b_2(\varphi_1) = l_0\sin\varphi_0 + l_1\sin\varphi_1 \qquad (6)$$

To find the angle φ_2, it isolated the terms which contains unknown φ_3, it multiply and adding those two equations. The obtained expression is a trigonometric with variable coefficient like bellow:

$$A_1(\varphi_1)\sin\varphi_2 + B_1(\varphi_1)\cos\varphi_2 = C_1(\varphi_1) \qquad (7)$$

The variable coefficients:

$$A_1(\varphi_1) = 2l_2b_2(\varphi_1);\ B_1(\varphi_1) = 2l_2b_1(\varphi_1);$$
$$C_1(\varphi_1) = l_3^2 - l_2^2 - b_1^2(\varphi_1) - b_2^2(\varphi_1) \qquad (8)$$

The equations solutions are:

$$\varphi_2 = 2\,\mathrm{arctg}\left(\frac{A_1 \pm \sqrt{A_1^2 + B_1^2 - C_1^2}}{B_1 - C_1}\right) \qquad (9)$$

$$\varphi_3 = 2\,\mathrm{arctg}\left(\frac{A_2 \pm \sqrt{A_2^2 + B_2^2 - C_2^2}}{B_2 - C_2}\right) \qquad (10)$$

where the variable coefficients for φ_3 have the expressions:

$$A_2(\varphi_1) = 2l_3b_2(\varphi_1);\ B_2(\varphi_1) = 2l_3b_1(\varphi_1);$$
$$C_2(\varphi_1) = l_2^2 - l_3^2 - b_1^2(\varphi_1) - b_2^2(\varphi_1). \qquad (11)$$

The coordinates of D point it calculates:

$$x_D = x_A + AD\cdot cos(\varphi_2 + \alpha_2) = l_1\cos\varphi_1 + l_2'\cos(\varphi_2 + \alpha_2); \qquad (12)$$

$$y_D = y_A + AD\cdot sin(\varphi_2 + \alpha_2) = l_1\sin\varphi_1 + l_2'\sin(\varphi_2 + \alpha_2). \qquad (13)$$

To determine the angle φ_0 (Figure 4) will calculate the length of A_0A_1 (Figure 5) in the triangle formed by points A_0, B_0, A_1 (A_1 = 900 angle measure). Angle φ_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: φ_0 calculated angle triangle $A_0B_0A_1$, variable coefficients and angles φ_2 and φ_3.

$$A0A1 := \sqrt{A0B0^2 - YB0^2} \qquad A0A1 = 11.832\cdot mm$$
$$\phi0 := asin\left(\frac{YB0}{A0A1}\right) \qquad \phi0 = 9.731\cdot deg$$
(14)

$$b1 := l0\cdot cos(\phi0) + l1\cdot cos(\phi1) \qquad b1 = 6.965\cdot mm$$
$$b2 := l0\cdot sin(\phi0) + l1\cdot sin(\phi1) \qquad b2 = 29.603\cdot mm$$
(15)

$$A1 := 2\cdot l2\cdot b2 \qquad A1 = 769.678\cdot mm^2$$
$$B1 := 2\cdot l2\cdot b1 \qquad B1 = 181.095\cdot mm^2$$
$$C1 := l3^2 - l2^2 - b1^2 - b2^2 \qquad C1 = -193.851\cdot mm^2$$
$$A2 := 2\cdot l3\cdot b2 \qquad A2 = 1.776\times 10^3\cdot mm^2$$
$$B2 := 2\cdot l3\cdot b1 \qquad B2 = 417.911\cdot mm^2$$
$$C2 := l2^2 - l3^2 - b1^2 - b2^2 \qquad C2 = -1.656\times 10^3\cdot mm^2$$
(16)

It notes in Mathcad with φ_{21} and φ_{22} the two solutions obtained for angle φ_2. It notes in Mathcad with φ_{31} and φ_{32} the two solutions obtained for φ_3 angle.

$$\phi21 := 2\,atan\left(\frac{A1 + \sqrt{A1^2 + B1^2 - C1^2}}{B1 - C1}\right) \qquad \phi21 = 152.568\cdot deg$$
$$\phi22 := 2\,atan\left(\frac{A1 - \sqrt{A1^2 + B1^2 - C1^2}}{B1 - C1}\right) \qquad \phi22 = 0.951\cdot deg$$
$$\phi31 := 2\,atan\left(\frac{A2 + \sqrt{A2^2 + B2^2 - C2^2}}{B2 - C2}\right) \qquad \phi31 = 101.601\cdot deg$$
$$\phi32 := 2\,atan\left(\frac{A2 - \sqrt{A2^2 + B2^2 - C2^2}}{B2 - C2}\right) \qquad \phi32 = 51.918\cdot deg$$
(17)

From condition like φ_2 and φ_3 being sharp angles, result that must keep only solutions $\varphi_2=0{,}951^0$ and $\varphi_3=51{,}918^0$.

$$xD2 := l1\cdot cos(\phi1) + l2'\cdot cos(\phi22 + \alpha2) \qquad xD2 = 26.067\cdot mm$$
$$yD2 := l1\cdot sin(\phi1) + l2'\cdot sin(\phi22 + \alpha2) \qquad yD2 = 32.089\cdot mm$$
(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 φ_1 = 100°. With SmartDimension command it determines and obtains the coordinates of D point: x_D = 26.0772 mm y_D = 32.0196 mm (Figure 6).

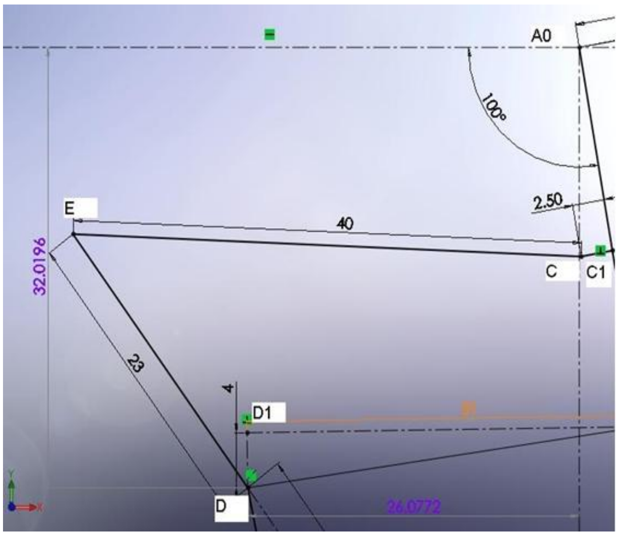


Fig. 6. The coordinates of D point display in SolidWorks

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).

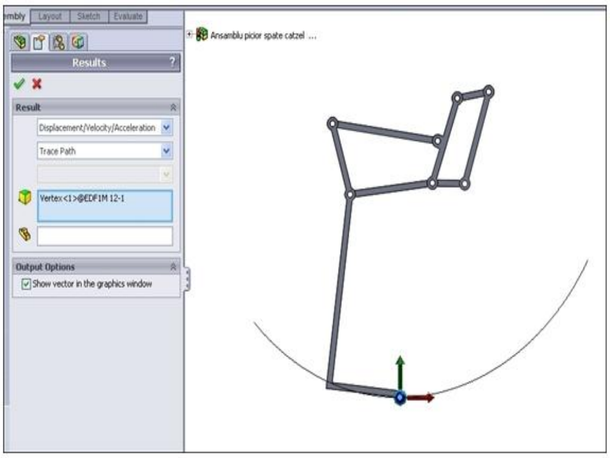


Fig. 7. The point contact soil trajectory, realized in CosmosMotion

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

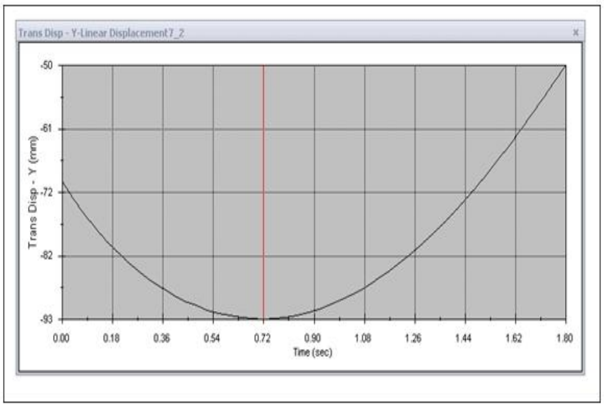


Fig. 8. The graphic of the point contact soil coordinates

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.

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