RESEARCH ARTICLE OPEN ACCESS

Implementation of an Algorithm for the Locomotion of Quadruped Robot with Bimorph Insect Leg.

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ABSTRACT
In the last decades the rising of higher processing power computers, together with more sophisticated robot actuators gave an impulse to the field of autonomous robots in robotics. The need to explore dirty, dangerous and difficult terrains is a suitable task for a robot, sparing a human from hazards of the environment. Even though wheeled robots have been used in great scale for explorations, its configuration has the downside of obstacle impediment and depending on the terrain its wheels can get stuck. The legged robot presents more versatility allowing him to surpass such obstacles in some cases. This article presents the continuation of the development of an quadruped robot with biomorphic insect leg.
***Keywords*–**Biomorphic, Locomotion, Insect, Quadruped, Robot.

I. INTRODUCTION

In the previous article [1] an method for analytical solving for a bimorph leg inspired in animals of the *insecta*class, more precisely in the *formicidae* family, was developed, yielding satisfying results. In this article a continuation of a legged robot prototype is given by implementing the bimorph legin a quadruped platform, and analysis of the physical system.

Nature always gave man an inspiration for machines designs, especially within the field of robotics such as the CWRU Robot III [2] that mimics the cockroach*BlaberusDiscoidalis*, from Case Western Reserve University, Massachusetts Institute of Technology Boadicea [3] also inspired by *BlaberusDiscoidalis*, and the most notable achievement, the Big Dog from Boston Dynamics.

In [4] a table for quadruped animalstogether with its locomotion patterns is presented, allowing a proper choice for the planned system. Since it's the beginning of a greater project it's reasonable that the first performed task of the proposed quadruped platform be walking before more complex operations be implemented, this being presented in the next sections.

II. MAIN PARAMETERS

For the given system an occupation factor β of 0.9 was chosen. Using two parameters for theWith this parameter is possible to define the time interval of the transfer functiont_t and sustentationt_s in terms of the period T by equations (1) and (2).

$$t_s = T * \beta \quad (1)$$

$$t_t = T * (1 - \beta) \quad (2)$$

Since there's two phases in the leg movement denoted here by transfer phase and sustentation phase, two polynomial functions were used to describe the foot trajectory. For the transfer phase a 6th degree polynomial (3) was chosen to reproduce a parabola and for the sustentation phase a 5th degree polynomial (4) to generate a straight line.

$$qs(t) = a0 + a1 * t + a2 * t^2 + a3 * t^3\ a4 * t^4 + a5 * t^5 \quad (3)$$

$$qt(t) = a0 + a1 * t + a2 * t^2 + a3 * t^3 + a4 * t^4 + a5 * t^5 + a6 * t^6 \quad (4)$$

To find the polynomials a_i-th coefficients a linear system was build using the first and second order derivative of these polynomials together with the defined points in "Table 1" and the times that they are supposed to happen in the leg period. In the derivatives that represent velocity and acceleration, the value is set to zero in the times in which we have the transition from sustentation to the transfer phase.

With this it was build a linear system of the type $A * X = B$. For the transfer function A, X and B is given by (5), (6) and (7). For the sustentation function we have that A, X and B assumes the values given by (8), (9) and (10). Heret_0,t_{hm},t_t, t_f denotes the initial, maximum height, transfer, and final period times respectively..

$$At = \begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 & t_0^4 & t_0^5 & t_0^6 \\ 0 & 1 & 2*t_0 & 3*t_0^2 & 4*t_0^3 & 5*t_0^4 & 6*t_0^5 \\ 0 & 0 & 2 & 6*t_0 & 12*t_0^2 & 20*t_0^3 & 30*t_0^4 \\ 1 & t_{hm} & t_{hm}^2 & t_{hm}^3 & t_{hm}^4 & t_{hm}^5 & t_{hm}^6 \\ 1 & t_t & t_t^2 & t_t^3 & t_t^4 & t_t^5 & t_t^6 \\ 0 & 1 & 2*t_t & 3*t_t^2 & 4*t_t^3 & 5*t_t^4 & 6*t_t^5 \\ 0 & 0 & 2 & 6*t_t & 2*t_t^2 & 20*t_t^3 & 30*t_t^4 \end{bmatrix} \quad (5)$$

$$Bt = \begin{bmatrix} Pi \\ 0 \\ 0 \\ Phm \\ Pf \\ 0 \\ 0 \end{bmatrix} \quad (6)$$

$$Xt = \begin{bmatrix} a0 \\ a1 \\ a2 \\ a3 \\ a4 \\ a5 \\ a6 \end{bmatrix} \quad (7)$$

$$As = \begin{bmatrix} 1 & t_t & t_t^2 & t_t^3 & t_t^4 & t_t^5 \\ 0 & 1 & 2*t_t & 3*t_t^2 & 4*t_t^3 & 5*t_t^4 \\ 0 & 0 & 2 & 6*t_t & 12*t_t^2 & 20*t_t^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2*t_f & 3*t_f^2 & 4*t_f^3 & 5*t_f^4 \\ 0 & 0 & 2 & 6*t_f & 2*t_f^2 & 20*t_f^3 \end{bmatrix} \quad (8)$$

$$Bs = \begin{bmatrix} Pf \\ 0 \\ 0 \\ Pi \\ 0 \\ 0 \end{bmatrix} \quad (9)$$

$$Xs = \begin{bmatrix} a0 \\ a1 \\ a2 \\ a3 \\ a4 \\ a5 \end{bmatrix} \quad (10)$$

III. TRANSLATION ON THE PLANE

For the plane translation on the mass center of the robot, the foot path chosen was a simple line parallel to the body of length 140 mm as shown in “Fig.1”.In the illustration Pi, Phm, and Pf denotes the initial, maximum height and final points respectively for the transfer phase of the leg. For each leg a table for the main points is given by:

Points	X	Y	Z
Pi1	13	4	-10
Pf1	13	-10	-10
Phm1	13	-3	-5
Pi2	13	-4	-10
Pf2	13	10	-10
Phm2	13	3	-5
Pi3	13	14	-10
Pf3	13	0	-10
Phm3	13	7	-5
Pi4	13	-14	-10
Pf4	13	0	-10
Phm4	13	-7	-5

Table 1 Pi, Phm and Pf for each leg

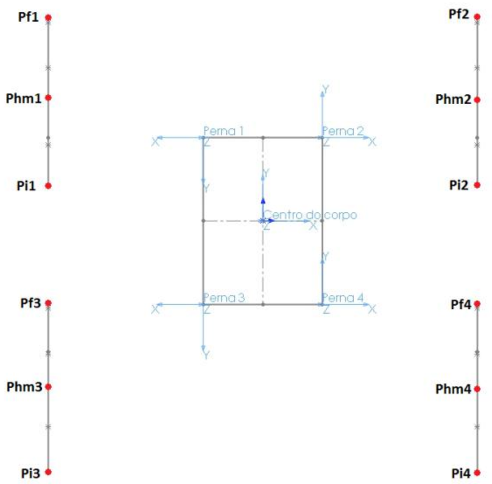

Fig.1Feettranslation curves on the plane

Solving for both linear systems with the given conditions the obtained the polynomial functions that define each coordinate of the leg foot on the body edge frame are given by (11), (12) and (13) and illustrated on “Fig 2”.

$$qx(t) = \begin{cases} 13 & for\ 0 \le t \le 3 \\ 13 & for\ 3 < t \le 30 \end{cases} \quad (11)$$

$$qy(t) = \begin{cases} 4 - 5{,}1851859 * t^3 + 2{,}5925926 * t^4 - \\ -0{,}3456790 * t^5 \quad for\ 0 \le t \le 3 \\ \\ -10{,}1372264 + 0{,}142907 * t + \\ -0{,}0515365 * t^2 + 0{,}0070539 * t^3 + \\ -0{,}0002324 * t^4 + \\ +0{,}0000022 * t^5\ for\ 3 < t \le 30 \end{cases} \quad (12)$$

$$qz(t) = \begin{cases} -10 + 11{,}852 * t^3 - 11{,}852 * t^4 + \\ +3{,}951 * t^5 - 0{,}439 * t^6\ \ for\ 0 \le t \le 3 \\ -10 \quad for\ 3 < t \le 30 \end{cases} \quad (13)$$

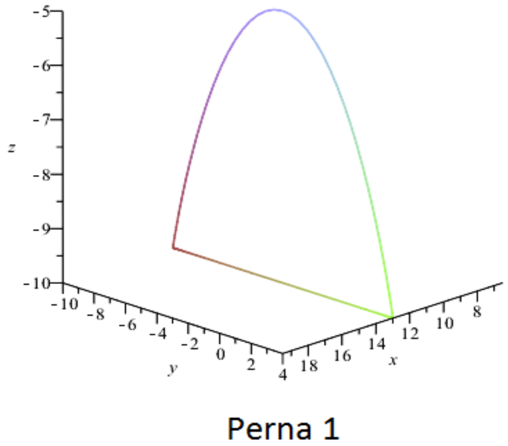

Fig.2 Foot trajectory

IV. ROTATION ON THE PLANE

For the body rotation movement the chosen trajectory for the robot feet was quarter of circumference as shown in “Fig.3” during the sustentation phase of the legs. For this trajectory the value of Z for the maximum height point was maintained.

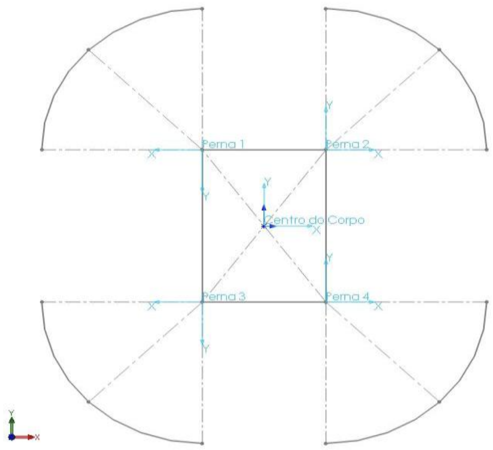

Fig.3 Feet trajectory for rotation.

Using the same strategy as the one for the translation of the plane the obtained foot trajectory for both transfer and sustentation phase of the movement is given by equations (14), (15) and (16), each representing the X,Y, Z coordinates of the foot in the space respectively. The foot trajectory is plotted in “Fig. 4”.

$$qrx(t) = \begin{cases} 13 * \cos\left(\frac{\pi}{6} * t - \frac{\pi}{2}\right) & for\ 0 \leq t \leq 3 \\ 13 * \cos\left(-\frac{\pi}{54} * t + \frac{\pi}{18}\right) & for\ 3 < t \leq 30 \end{cases} \quad (14)$$

$$qry = \begin{cases} 13 * \sin\left(\frac{\pi}{6} * t - \frac{\pi}{2}\right) & for\ 0 \leq t \leq 3 \\ 13 * \sin\left(-\frac{\pi}{54} * t + \frac{\pi}{18}\right) & for\ 3 < t \leq 30 \end{cases} \quad (15)$$

$$qrz(t) = \begin{cases} -10 + 11{,}852 * t^3 - 11{,}852 * t^4 + \\ + \ 3{,}951 * t^5 - 0{,}439 * t^6 \quad for\ 0 \leq t \leq 3 \\ -10 \quad for\ 3 < t \leq 30 \end{cases} \quad (16)$$

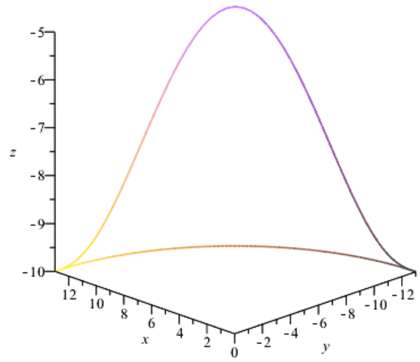

Fig.4Foot trajectory3during rotation

V. PHYSICAL ROBOT

For the platform implementation were used an Arduino Mega 2560 to realize the algorithm computation that outputs the angles for each Herkulex servo that were previously addressed in the code. The CAD project can be seen together with the physical platform in “Fig.5” and “Fig.6”

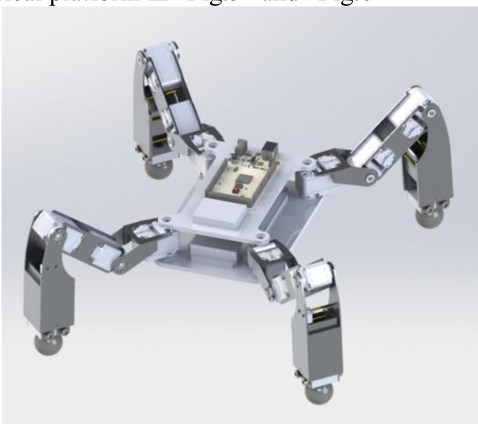

Fig.5 CAD project

Fig.6Physical platform

The platform performed on a flat ground the translation operation, and posteriorly an 90º degrees body rotation."Fig.7" and "Fig.8" illustrates respectively the robot response for each operation.

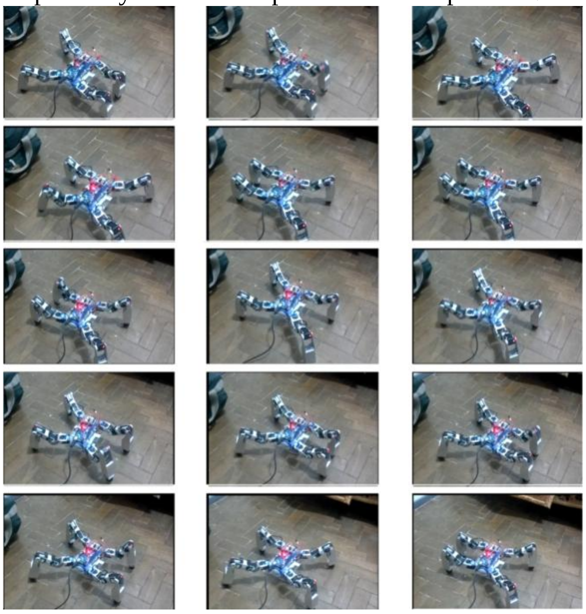

Fig.7 Forward walking

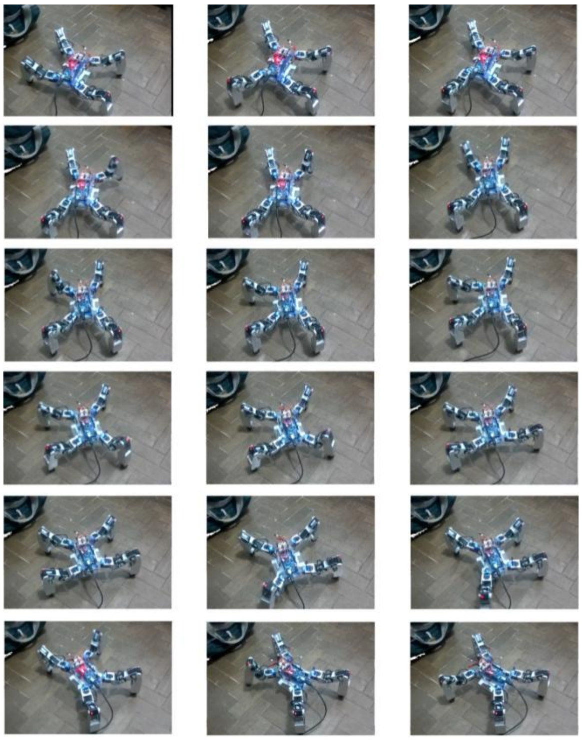

Fig.8 Counter-clockwise rotation

VI. CONCLUSIONS

The project achieved its goal of successfully implementing a biomorphic leg in a robot capable of locomotion in a plane environment. Even though the robot was inspired in living creatures, its structure doesn't have an know equivalent animal, indicating that the locomotion pattern may not be exclusive for an organic or artificial form and that some of these patterns can be applied to robots with different shape than those of the original animal.

There is now for this platform a great gamma of improvements that can be made, such as the addition of an computer vision system together with an artificial intelligence algorithm that will allow the robot to generate planned paths through motion planning. Such improvements will be left for later studies.

Acknowledgements

The authors would like to thank the generous support of the "Pontifícia Universidade Católica de Minas Gerais", the "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–CAPES,"the "Conselho Nacional de Desenvolvimento Científico e Tecnológico–CNPq," andthe "Fundação de Amparo a Pesquisa de Minas Gerais–FAPEMIG".

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