Modeling and optimization with genetic algorithms of quasi-static gait patterns in planar biped robots

Marco Antonio Meggiolaro, Mauro Speranza Neto, Alexis López Figueroa

***Abstract*— This work deals with the kinematic and static modeling of a planar biped robot, aiming to optimize quasi-static gait patterns. The gait patterns are evaluated and optimized using genetic algorithms to minimize the relationship between the energy consumed by the robot motors and the displacement obtained in each robot step, always guaranteeing static equilibrium within a safety margin. The evolution of the different joint angles for the gait patterns are indirectly stored by adjusting the coefficients of polynomial or trigonometric functions. In addition, two different approaches are explored for the genetic algorithms: one aiming to optimize a complete step from the gait, and other to independently optimize sub-step within each step. The gait pattern obtained decreased the energy/displacement ratio by up to 18% with respect to other non-optimized patterns. The best pattern has been programmed into a Bioloid GP robot to physically validate the gait stability on a planar surface without obstacles.**

***Index Terms*— Biped robot , Gait pattern, Genetic algorithms, Optimization.**

I. Introduction

Design a robot that can duplicate the complex human movements and help people in different situations, be of assistance, cooperation or replacement in high-risk tasks, is one of the main objectives for which humanoid robotic´s has more investments and advances everyday.

Initially, the generation and optimization of bipedal quasi-static gait patterns, with the intention to carry delicate load on uniform ground, in which one needs smooth, slow movements and rational use of batteries in relation to the space traveled.

The basic assumptions are:

Quasi-static walk, i.e. should the movement is stopped, the structure ought to remain balanced, because the center of mass is within the robot´s feet rest polygon at all times.

The mathematical modeling is kinematic. Therefore, there are not considered dynamic conditions.

Simulations do not prevent collisions between the robot parts or the environment, since it does not have collision detector.

The walking robot is on even ground without obstacles.

Ground contact has no sliding.

Feet are restricted to remain horizontal and the trunk 90º vertical, and it is considered that it produces no external moment on the hip.

A physical biped model is only used to play the gait pattern provided in open loop, i.e. has no control implementation in hardware.

II. Plane Biped Robot

A plane biped robot is one that moves on two legs with movements in one plane. The system treated in this document is not humanoid, i.e., has no arms or head, consisting solely of legs and hips.

A. *Physical biped robot simulation Representation*

Fig. 1 shows the biped robot physically mounted [1] and a draft made in Matlab, which was used in simulations Fig. 2a) relate each link of the robot with the name of the equivalent human body parts, for greater familiarity; and Fig. 2b) relate motors and centers of mass of the links. The robot has six motors, three for each leg located in the ankle, knee and hip.

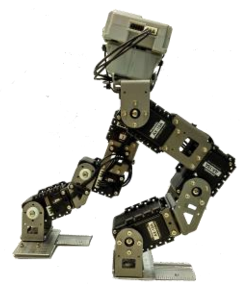
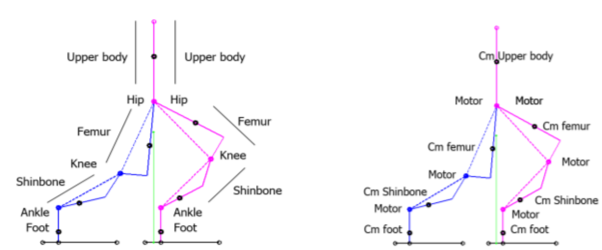


Fig. 1. Biped robot used



a) b)

Fig. 2. Representation of the physical biped robot in simulation.

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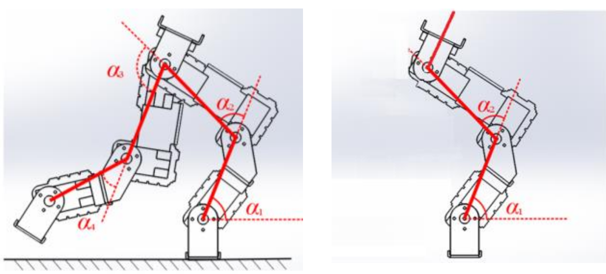
B. Definition angles

1) Simplified angles α

For ease of computational cost, it is important to reduce the number of variables involved in gait representation. The robot trunk angle is independent of the angle between the femurs, and feet are restricted to be horizontal. Additionally, in two dimensions the robot has five key elements, which to be joined serially with straight lines allow the representation as a serial robot manipulator with four degrees of freedom, as shown in Fig. 3a). The points are: foot ankle standing on the ground; knee of the supporting leg; hip; leg knee in the air; and ankle foot in the air, with motors at all points except the last. The angles of the actuators are α1, α2, α3 e α4, respectively.

Fig. 3b) for the phase 2 shows the points on the foot ankle that is on the ground. The knee of the supporting leg, and hip, with angles of equal engines α1 and α2, where the legs are treated as two independent handlers [2].



a) b)

Fig. 3. Simplified angles α.

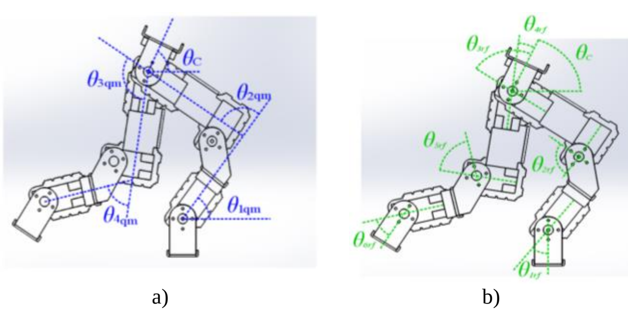
2) Transition angles θ_{qm}

Transition angles θ_{iqm} showed in Fig. 4a) They are intermediate angles that allow turning angles α in real angles of the physical motors and vice versa. Equation (1) links α with θ_{qm}.

$$\begin{aligned}
\theta_{1qm} &= \alpha_1 - 17° \\
\theta_{2qm} &= \alpha_2 + 35.42° \\
\theta_{3qm} &= \alpha_3 \\
\theta_{4qm} &= \alpha_4 - 35.42°
\end{aligned} \tag{1}$$

3) Motor physical angles θrf

Fig. 4b) shows the actual angles of the motors which are used to controls them. Equation (2) expresses the relationship between these angles and transition angles (or intermediate).



a) b)

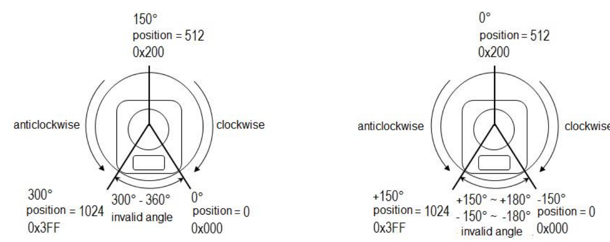
Fig. 4. Representation of the angles of the physical biped robot.

$$\begin{aligned}
\theta_{1rf} &= 90 - \theta_{1qm} \\
\theta_{2rf} &= \theta_{2qm} \\
\theta_{3rf} &= \theta_C - \theta_{1qm} - \theta_{2qm} \\
\theta_{4rf} &= -\theta_C - 180 + \theta_{1qm} + \theta_{2qm} + \theta_{3qm} \\
\theta_{5rf} &= -\theta_{4qm} \\
\theta_{6rf} &= -270 + \theta_{1qm} + \theta_{2qm} + \theta_{3qm} + \theta_{4qm}
\end{aligned} \tag{2}$$

where θ_c is the angle of the trunk to the horizontal, and θ_{qm} is transition angle.

4) Programming Angles

The motors used have a default setting angles and equivalent positions to be programmed in decimal or hexadecimal system, as presented in Fig. 5a) [3]. These angles have been changed, to continue the nomenclature commonly used in the literature [4],[5] as shown in Fig. 5b). The lower degree (0°) becomes -150°, equivalent to zero (0) in decimal or hexadecimal, as a programming input value; and the maximum (300°) becomes +150°, equivalent to 1024 in decimal or in hexadecimal 3FF. The relationship of the decimal position of the motor and adjusted angle is a linear relationship is expressed in (3).



a) b)

Fig. 5. Angles programming

$$P_D = 3.41\theta_{rf} + 511.5 \tag{3}$$

where P_D is the position in decimal notation and θ_{rf} angle θ physical robot.

C. Kinematics, Denavit-Hartenberg (DH) parameters

The biped robot was designed as a series of 12 straight links. The DH parameters [6],[7] for direct kinematics, of the links are shown in Table I.

To find the points representing the centers of mass, is taken up the immediately preceding reference system and apply their rotations and translations for the new system. The parameters for each mass center are shown in Table II.

TABLE I
DH PARAMETERS FOR ORIGINS OF COORDINATED SYSTEMS

	d_i	θ_i	a_i	β_i	A_i^{i-1}
1	0	90°	L_p	0	A_1^0
2	0	$-\theta_{1rf}$	L_{1a}	0	A_2^1
3	0	45°	L_{1b}	0	A_3^2
4	0	$-135°-\theta_{2rf}$	L_{2a}	0	A_4^3
5	0	90°	L_{2b}	0	A_5^4
6	0	θ_{3rf}	L_t	0	A_6^5
7	0	180°	L_t	0	A_7^6
8	0	θ_{4rf}	L_{3a}	0	A_8^7
9	0	-90°	L_{3b}	0	A_9^8
10	0	$135°-\theta_{5rf}$	L_{4a}	0	A_{10}^9
11	0	-45°	L_{4b}	0	A_{11}^{10}
12	0	$-\theta_{6rf}$	L_p	0	A_{12}^{11}

A_i^{i-1}= orientation relationship matrix and position between two coordinate systems O_{i-1} and O_i, d_i= distance in Z axis, θ_i= angle between X axis, θ_{rf}= θ physical robot angle, a_i= distance in X axis, β_i= angle between Z axis.

TABLE II
DH PARAMETERS FOR MASS CENTERS

	d_i	θ_i	a_i	α_i	A_{cmj}^i
cm1	0	90°	L_{cm1}	0	A_{cm1}^0
cm2	0	$-\theta_{1rf}$	L_{cm2}	0	A_{cm2}^1
cm3	0	90°	L_{cm3}	0	A_{cm3}^4
cm4	0	θ_{3rf}	L_{cm4}	0	A_{cm4}^5
cm5	0	θ_{4rf}	L_{cm5}	0	A_{cm5}^7
cm6	0	-45°	L_{cm6}	0	A_{cm6}^{10}
cm7	0	$-\theta_{6rf}$	L_{cm7}	0	A_{cm7}^{11}

A_{cmj}^{i-1}= orientation relationship matrix and position between two coordinate systems O_{i-1} and O_{cmj}, d_i= distance in Z axis, θ_i= angle between X axis, θ_{rf}= θ physical robot angle, a_i= distance in X axis, β_i= angle between Z axis.

The origins of coordinate systems of the two previous tables are shown in Fig. 6a), The distance a_i is shown in Fig. 6b) and Fig. 6c), and θ_{irf} angles are shown in Fig. 6d).

The general center of mass of the biped robot is calculated with (4), where the vector r_{cm} (mass center position) is equal to the summation of the product i_{th} mass link m_i times its vector r_i position, divided by total mass [8].

$$r_{cm} = \frac{\sum_i m_i r_i}{\sum_i m_i} \tag{4}$$

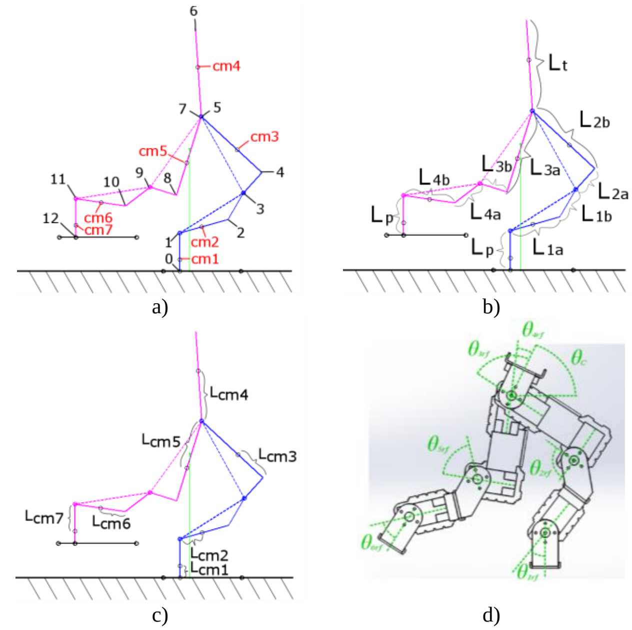


Fig. 6. DH parameters in the representation of biped robot.

The initial simplified simulation display was using four links and the four α angles. The links are the represented by dotted lines as shown in Fig. 6a). The simplified direct kinematic shows the position of the extreme coordinate (Xext, Yext) shown in Fig. 7 by (5), The position of the hip is shown by (6), and the 'Jacobian' matrix, that lists the links´ speeds standing on the floor with the speed of the hip is expressed in (7).

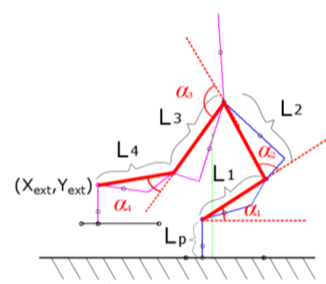


Fig. 7. Simplified kinematics representation

$$\begin{aligned} X_{ext} &= L_1 cos\alpha_1 + L_2 cos(\alpha_1+\alpha_2) + L_3 cos(\alpha_1+\alpha_2+\alpha_3) + L_4 cos(\alpha_1+\alpha_2+\alpha_3+\alpha_4) \\ Y_{ext} &= L_1 sin\alpha_1 + L_2 sin(\alpha_1+\alpha_2) + L_3 sin(\alpha_1+\alpha_2+\alpha_3) + L_4 sin(\alpha_1+\alpha_2+\alpha_3+\alpha_4) \end{aligned} \tag{5}$$

$$\begin{aligned} X_{quadril} &= L_1 cos\alpha_1 + L_2 cos(\alpha_1+\alpha_2) \\ Y_{quadril} &= L_1 sin\alpha_1 + L_2 sin(\alpha_1+\alpha_2) \end{aligned} \tag{6}$$

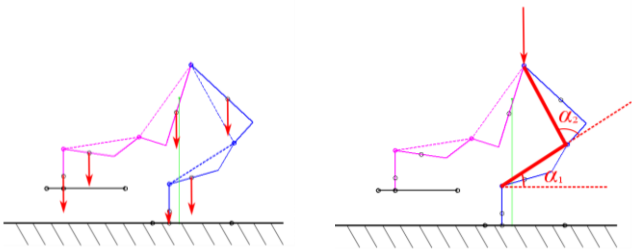
$$J_{quadril} = \begin{bmatrix} -L_1 sin\alpha_1 - L_2 sin(\alpha_1+\alpha_2) & -L_2 sin(\alpha_1+\alpha_2) \\ L_1 cos\alpha_1 + L_2 cos(\alpha_1+\alpha_2) & L_2 cos(\alpha_1+\alpha_2) \end{bmatrix} \tag{7}$$

D. *Statics*

The modeling of the robot is made assuming a quasi-static situation; i.e. whether it is stopped or in movement, the structure should remain balanced for setting angles provided by the running pattern generator, because the center of mass should be within the supporting polygon at all times.

The calculated torques are calcualted to overcome the weight of each link, and an external force representing the weight of the upper body in a biped robot. It is applied at the hip in the vertical direction, since it is fixed at 90° of the body, and it is considered that it doens not produce external moment on the hip.

The forces are shown in Fig. 8, The gravitational force and torques at the hip are calculated with (8) e (9) [4]. For the double support stage, the weight is equally divided between the two legs, represented as two independent serial manipulators "connected" at the extreme.



a) b)

Fig. 8. Static equilibrium.

$$G_i = \sum_{j=1}^{n} m_j * g^T * J_{Li}^{(j)} \tag{8}$$

Where "G" is the motor torque produced by gravity, m is the mass of the link, g is the gravity and J is the Jacobian matrix of the center of mass of the links, given by

$$\tau = J^T * F \tag{9}$$

Where τ is the torque produced by the external force, J is the Jacobian matrix at the point where the force is applied, and F is the external applied force.

III. Genetic Algorithms

Genetic algorithms, GA are search and highly parallel optimization techniques inspired by the principle of natural selection and genetic reproduction of Charles Darwin [9], [10], where the fittest individuals and greater longevity of the population are more likely to reproduce and perpetuate their genetic codes on the next generations. Such genetic codes constitute the identity of each individual, and are represented in the chromosomes [11].

The chromosome is the data structure that characterizes the individual or possible solution to the problem of the search space. It is subjected to an evolutionary process involving evaluation, selection, recombination, mutation and replacement. After several cycles or evolution and generations, the population should contain the fittest individuals. Fig. 9 shows in general the evolutionary process of the genetic algorithm [12].

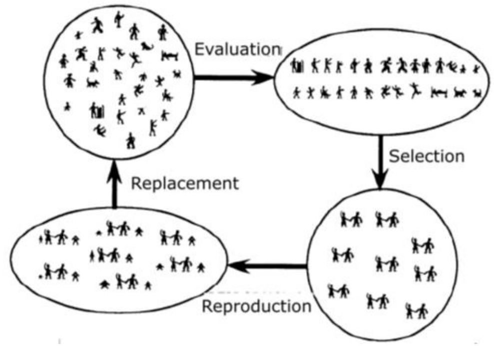


Fig. 9. Evolutionary process of GA

The evaluation is the connection between the GA and the problem, which provides a quantitative value to the subject called fitness. Fitness is how suited is or how good an answer to the problem this subject, characterized by a specific function or objective function.

Selection is the process by which individuals are sought for reproduction and those with higher fitness are more likely to be chosen. The selection operator typically used in GAs is roulette, where each individual is represented with a proportional band to its relative fitness on a disk that rotates. The main selection mechanisms are proportional, for tournaments, with truncation, and linear normalization and exponential [13].

The process of recombination or playback using the operator "crossover", considered the key feature in the AGs: pairs of parents chosen individuals of the population called parents contribute genetic material or information to create different new subjects called children, which share characteristics of both parents. The main crossover operators are one point, two points and uniform.

Mutation is an exploratory operator because it causes data to disperse over the search space modifying a value in this chromosome if it was selected for change.

Replacement is the process where individuals, who will continue in the next generation, are selected. The most known methods are: exchange of the entire population, in which new individuals replace all previous population; exchange of the entire population with elitism, in which all chromosomes are replaced by the fittest chromosome from current population; partial exchange of the population, in which there are only exchanged the worst individuals and maintained the best; and finally partial exchange of the population without duplicate where the duplicated chromosomes are also exchanged, in addition to the worst ones.

A. Generation of variables using GA

It was sought to discover the setting angles that produce a pitch with the lowest power consumption compared to the foot shift, keeping the center of mass within the space covered by the support, as shown in the Fig. 10, thus keeping balance quasi-static.

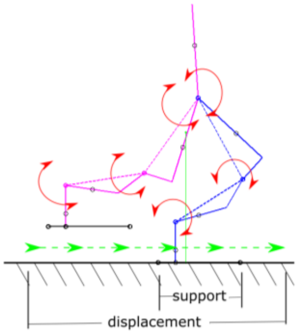


Fig. 10. GA goal for the movements of the biped robot.

Robot movement was constructed by film frames, where each frame is a setting angle, as shown in Fig. 11.

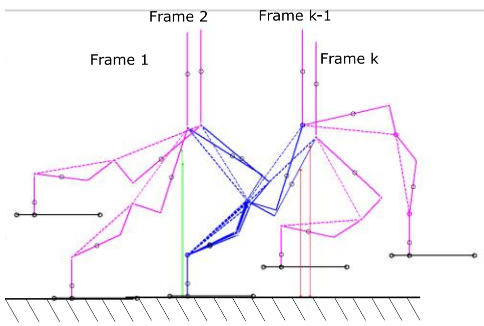


Fig. 11. Successive frames

B. Fitness function

The fitness function (f_1) to be minimized to walk is shown in (10), It connects mechanical and electric power consumed by the motors plus penalties, if any. Mechanical energy is the product of the torque τ in the motor and the angular velocity ω at time t, while the power is the product of the motor's internal resistance *R* and the electric current *i* squared at time *t* [14].

$$f_1 = \frac{\sum_{1}^{k}\left(\sum_{1}^{6}\tau*\omega+R*i^2\right)*\Delta t}{D}+Penalties \tag{10}$$

Experiments were not conducted to get such data. Instead, it was used the manufacturer's data and the characterization made by Mensink “Dynamixel AX-12” [15], [3].

C. Penalties on individuals

They were considered situations that cannot be allowed to the individual in the robot configuration. Should this happen, they are punished, establishing they are not acceptable angles. Penalties are applied when:

- The Y position of the hip goes out of the considered height range.
- The foot does not move toward positive X, ie if it does not go forward.
- The position of the Y coordinate of the foot is negative, which means that the foot is below ground, which is impossible.
- The center of mass is outside the area covered by the footrest, meaning a fall.
- The foot does not move in the Y direction, is positive if it is to rise, is negative if it is to go down.

Such penalties are shown in Fig. 12.

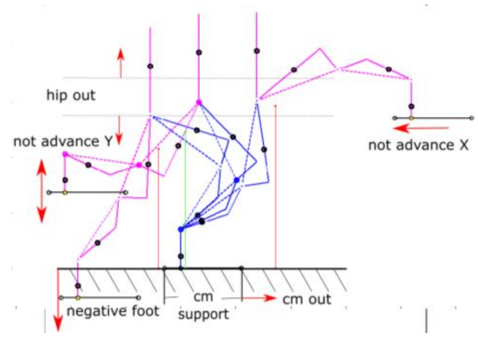


Fig. 12. Penalties, biped movements

D. Chromosome Configuration

To reduce the computational cost of the walking program, it was decided to take the representation of six motors with four variables to reduce the number of variables in the search space (α simplified angles). Four chromosome representations were used to generate the motors´ angles for each frame, so named: polynomial function, cosine function, full step, and sub-step.

1) Chromosome polynomial function

Accordingly, the angles are provided by a sith deree polynomial, where each polynomial has seven coefficients, for a total of 28 variable chromosomes adjusted by GA. Table III shows the structure and (11) angles for this case.

TABLE III
CHROMOSOME POLYNOMIAL

Chromosome																
θ1					θ2					…	θn					
a_0	a_1	a_2	….	a_m	a_0	a_1	a_2	….	a_m	…	a_0	a_1	a_2	…	a_m	

a= coefficients.

$$\theta_n = a_0 + a_1 * k + a_2 * k^2 + a_3 * k^3 + \ldots + a_m * k^m \tag{11}$$

where k is the frame.

2) Chromosome trigonometric function (cosine)

In this case, the angles are provided by a cosine function with four coefficients into a chromosome for a total of 16 variables set by GA. Table IV presents the structure and (12) shows the angles in this case.

TABLE IV
CHROMOSOME COSSINE

Chromosome												
θ_1				θ_2				…	θ_n			
a	b	c	d	a	b	c	d	…	a	b	c	d

a= coefficients.

$$\theta_n = a + b * cos(c * k + d) \tag{12}$$

Where a is the vertical movement, b is the amplitude, c is the frequency, d the phase or vertical shift and k the frame.

3) Chromosome full step

In this case, the angles are provided directly by the GA. The chromosome is configured with 120 variables corresponding to 30 consecutive positions by four motors. Table V presents the structure and (13) shows the result angles.

TABLE V
CHROMOSOME FULL STEP

Chromosome												
Frame 1				Frame 2				…	Frame k			
θ1	θ2	θ3	θ4	θ1	θ2	θ3	θ4	…	θ1	θ2	θ3	θ4

$$\begin{aligned} \theta_1(k) &= (4*k)-3 \\ \theta_2(k) &= (4*k)-2 \\ \theta_3(k) &= (4*k)-1 \\ \theta_4(k) &= (4*k) \end{aligned} \tag{13}$$

Where k is the frame.

This setting is the one that has greater scope in the search space, as it admits that the variables of individuals can have all possible allowed values. That is, it allows the end of the foot can be anywhere in the X - Y plane as the drive angle may be any function. Fig. 13 presents foot´s possible trajectories for different chromosomes.

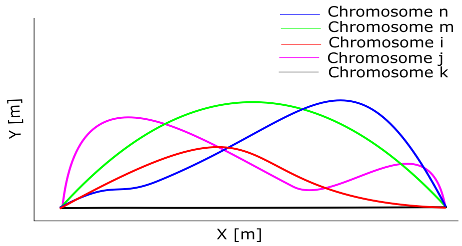


Fig. 13. Possible foot ´s trajectories for different chromosomes

4) Chromosome sub-step

In this representation, the angles are provided directly by the GA. Yet, the chromosome is configured here with only 4 variables in each frame by an increase in sub-steps. This is the construction of a complete walk starting from developments (sub-steps) from the previous position. Each link has a range of motion between [-θ, + θ] where the GA determines which angle settings has the lowest energy ratio of displacement from the previous position; ie, each setting is an incremental evolution.

The frames are calculated until the foot position is less than an arbitrary percentage of the overall distance from the goal, which for this robot was 5mm.

Table VI presents the structure of the chromosome for each frame, and Fig. 14 shows a representation of possible behavior during successive evolutions.

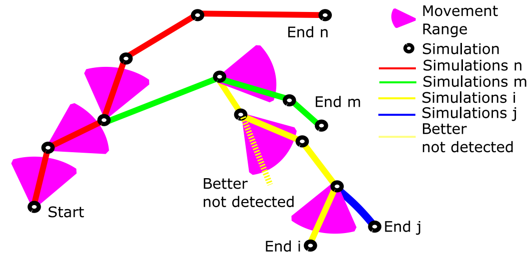


Fig. 14. Possible trajectories of the foot to different chromosomes

From the starting point in Fig. 14, one can observe that the range of movement during a sub-step of simulating a response is chosen and, starting from this, another is immediately sought.

Fig. 15 shows possible foot paths built with successive evolutions sub-step.

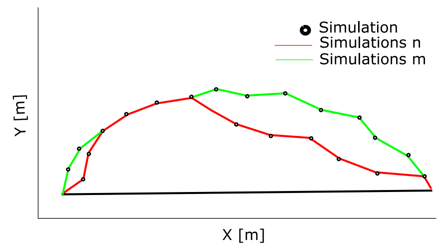


Fig. 15. Possible foot trajectories built with sub-step

IV. RESULTS

For individual simulations it was determined that the time between the frames would 0.1s, and the time for a step 4s, because during the initial tests on the physical robot was observed that a shorter time considerably affects the quasi-static condition ie, faster movements make the robot to fall as the foot is not secured to the ground.

It is called one step the executing of phase 1 and phase 2, the executing of two steps for a total angle´s chart time of each motor, equivalent to 8 seconds. The computer features in which the programs were run are: processor "i7-5950HQ" 2.9GHz clock speed, RAM 16Gb, operating system "Windows 10".

A. Polynomial function

The polynomials coefficients were adjusted by the GA. The penalized settings were: negative foot (below the ground), mass center outside the projection stability, and hip level (to be controlled). The GA parameters were: 8000 generations, population 3000, roulette selection, mutation, two points 65% and crossover 5%. The computational calculation 93.573s time was approximately 26 hours.

Fig. 16 shows the response of the foot path in a step to the calculated angles with the polynomial (11) coefficients adjusted by GA.

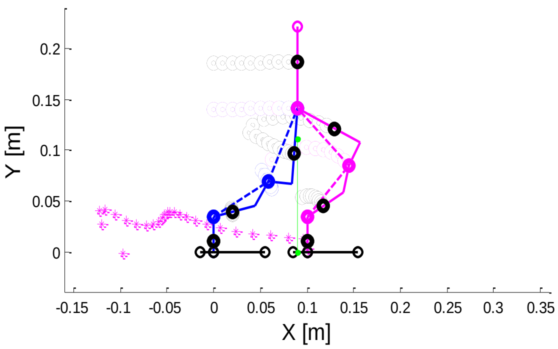


Fig. 16. GA response polynomial function

Fig. 17 shows the increase on energy consumed during two steps and the biped configuration in an instant of time.

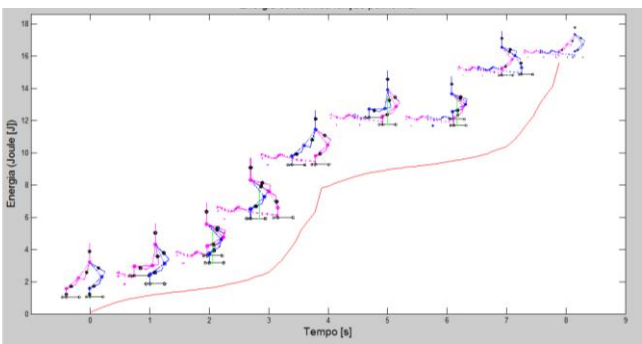


Fig. 17. Energy consumed, polynomial function

The energy consumed during the gait pattern for the period was 15,61J and the energy ratio of displacement was 39,5J / m.

Fig. 18 shows the evolution of the foot trajectory.

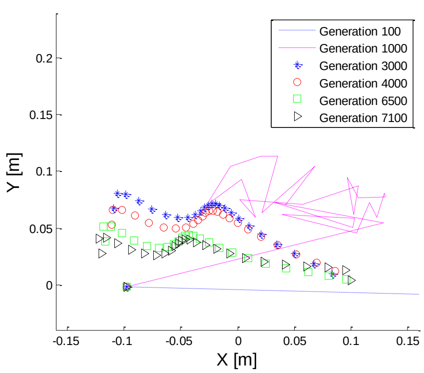


Fig. 18.Evolution of the foot trajectory, polynomial function

B. *trigonometric function (cosine)*

In this case, they were used trigonometric functions (cosine) and coefficients were adjusted by the GA. The penalized settings were: negative foot, the center of mass out and hip level. The GA parameters were also the same. The computational calculation time was 33.796s, about 9 hours and 15 minutes.

Fig. 19 shows the response of the foot trajectory in a step to the calculated angles with the cosine function (12) coefficients adjusted by GA.

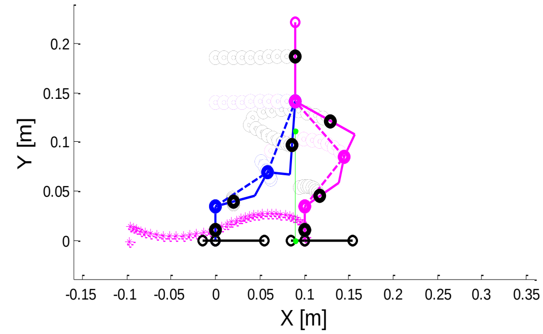


Fig. 19. GA response cosine function

Fig. 20 shows the consumed energy increase during two steps with the robot configuration biped at the time.

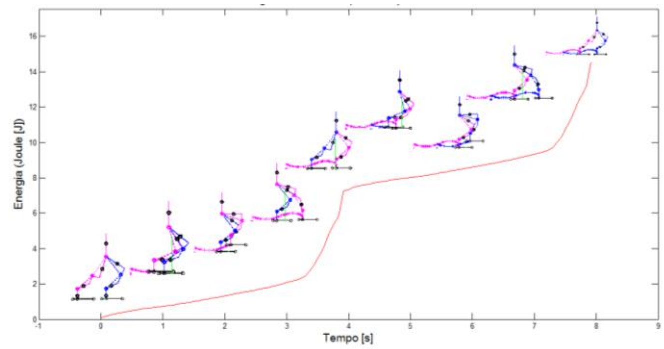


Fig. 20. Energy consumed, cosine function

The energy consumed during the gait pattern for the period was 14,55J and the energy ratio of displacement was 36,8J / m.

Fig. 21 shows the evolution of the foot trajectory.

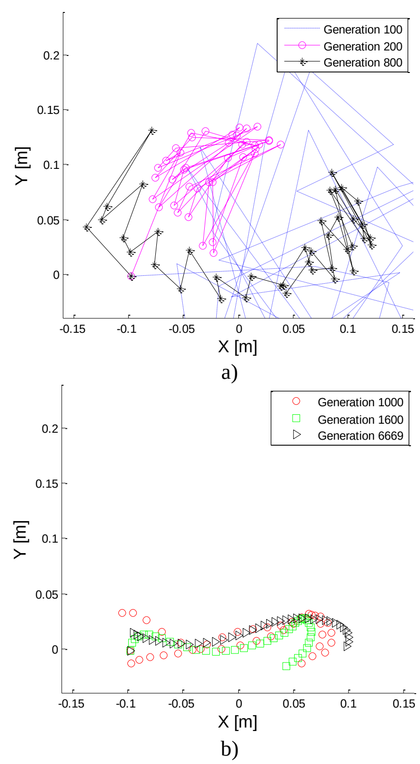


Fig. 21. Evolution of the foot trajectory, cosine function

C. Complete Step A

For this form of step representation, the penalized settings were: the foot does not move in the X direction, the position of the Y coordinate of the foot is negative, the center of mass is outside the area covered by the footrest, the Y position of the hip goes out of the considered height range. GA parameters were the same above: generations 8000, 3000 population, Roulette selection, 65% data mutation, and 5% crossover. The computational calculation 649.586s time was approximately 7.5 days

The consumed energy during the gait pattern for the period was 13,89J and the energy ratio of displacement was 35,2J / m.

This response hardly lifts his feet off the ground to save energy, almost dragging on the ground.

Physically it was impossible to implement this response in biped robot mounted because it has a side support for the feet, as previously shown in Fig. 1, It would produce a collision between two feet and eventually fall. For this reason, a penalty was added: the foot does not move in the Y direction is positive if to climb, is negative if it is to descend.

D. Complete Step B

In this case, a penalty was added configuration: the foot does not move in the positive direction Y when X <0, if the foot does not move in the negative Y direction when X> 0. The GA parameters were the same earlier. The computational calculation 499.506s time was approximately 6 days.

Fig. 22 shows the response of the foot path in a step to the angles provided directly by GA.

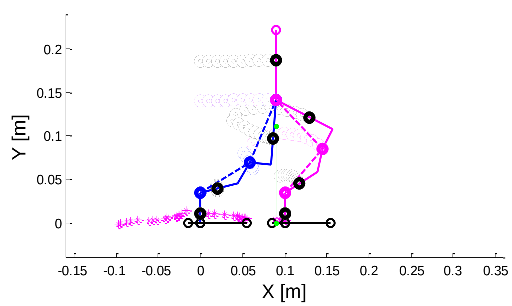


Fig. 22. GA response full step B

Fig. 23 shows the increase of consumed energy during two steps and the biped configuration at any time.

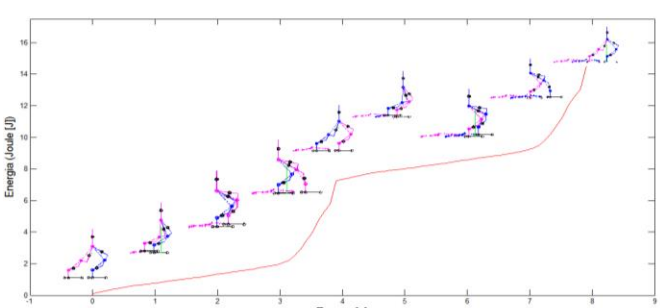


Fig. 23. Energy consumed, full step B

The energy consumed during the gait pattern for the period was 14,5J and the energy ratio of displacement was 36,7J / m.

Fig. 24 shows the evolution of the foot trajectory.

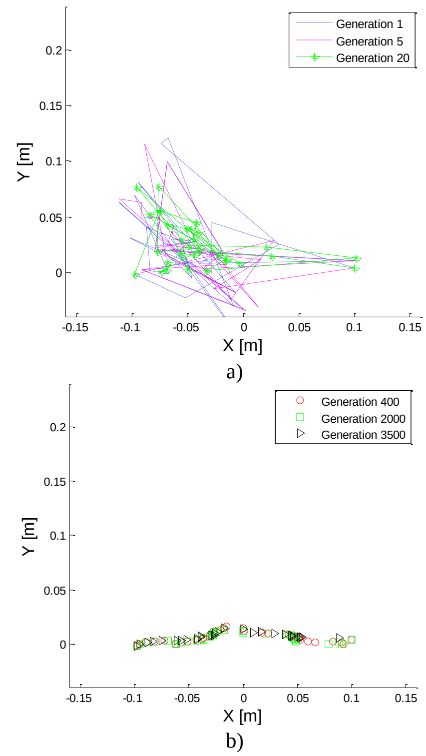


Fig. 24. Evolution of the foot trajectory, full step

E. Sub step A

In this case, the penalized settings were: foot does not move in the X direction, the position of the Y coordinate of the foot is negative if the center of mass is outside the area covered by the footrest, the Y position of the hip goes out the height range. They used the same previous GA parameters. The computational calculation time was 13528s, about 3 hours and 45 minutes.

The energy consumed during the gait pattern for the period was 14,08J at a distance 0,391m, and the energy ratio of displacement was 36,05J / m

The response sub-passed does not chart general evolution, since it is a building with successive evolutions for each frame.

Physically it is not possible to implement this response because the end biped has mounted lateral support on the feet, as mentioned before. For this reason, a penalty was added if the foot does not move in the Y direction is positive if to climb, is negative if it is to descend, as described below called response B.

F. Sub-step B

In this case, a penalty configuration was added: the foot does not move in the positive direction Y when X <0, if the foot does not move in the Y negative direction when X> 0. The GA parameters were the same. The computational calculation 17.849s time was approximately 5 hours. Fig. 25 shows the response of the foot trajectory in a step angles provided by GA.

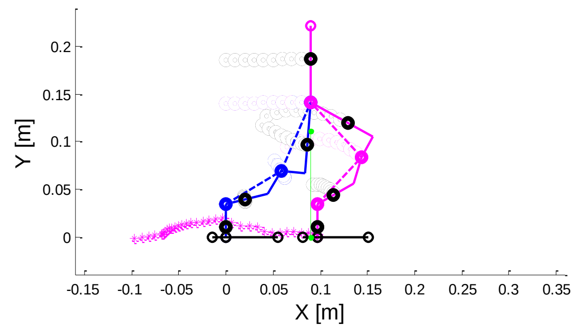


Fig. 25. GA response sub-step B

Fig. 26 shows the increase in consumed energy during two steps biped configuration at any time.

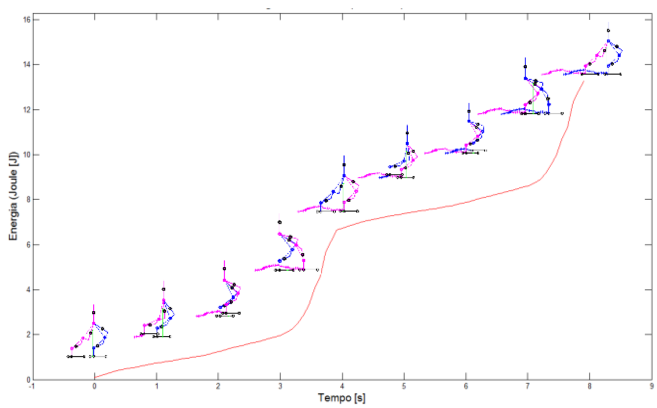


Fig. 26. Energy consumed, sub-step B

The energy consumed during the gait pattern for the period was 13,29J displacement was 0,388m, the energy ratio of displacement was 34,25 J / m.

G. *Best individual*

Fig. 27 presents the foot trajectories for the responses in found step angles according to the various configurations of the chromosome to the GA proposed in this work.

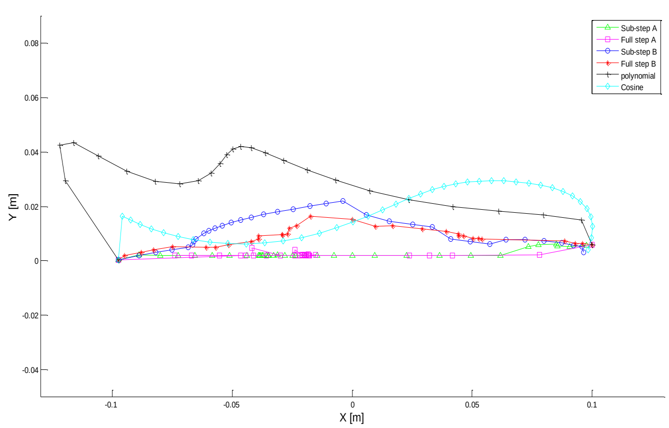


Fig. 27. GA responses, foot trajectories

Table VI presents a summary of the response data. It compares the relative displacement energy and it is observed that the best answer is GA with sub-step in response B, with energy consumption of 13.29 J, displacement of 0.388 meters and relative energy of 34.25 displacement J / m. Another advantage of the approach with sub-step was the lowest time of calculation, compared with the method applying GA to full step.

TABLE VI
SUMMARY GA RESPONSES

Config.	**F**	**Ts [s]**	**D [m]**	**E [J]**	**E/D**	**Tc**
Heuristic	21	0,19	0,395	16,5042	41,77	not applicable
Polynomial	36	0,11	0,395	15,6079	39,5017	26 h
Cosine	51	0,07	0,395	14,5548	36,8366	9 h 15 min
Full step A	42	0,09	0,395	13,8944	35,1652	7,5 d
Sub-step A	40	0,10	0,390	14,0798	36,0517	3 h 45 min
Full step B	42	0,09	0,395	14,497	36,6902	6 d
Sub-step B	45	0,08	0,388	13,2922	34,2515	5 h

Config. = chromosome configuration, F= frame, Ts= sample time, D= displacement, E= energy consumed, E/D= relationship between energy consumed and displacement, Tc= computing time.

V. CONCLUSIONS

This work was mounted a planar biped robot prototype, in order to reproduce the angles provided for it by simulations and physically validate the stability of the quasi-static walking on a flat surface without obstacles.

It was also observed the walk of a chicken as a guide for obtaining a quasi-static gait in heuristic mode; simulated in "Matlab" and "Solidworks". The angles were implemented in the prototype and were determined conditions for the GA.

The simulations in "Matlab" were built using kinematic and static modeling.

There were generated gait patterns with GA aiming at four different chromosome configuration options: indirectly with the adjustment of polynomials and trigonometric functions; and directly with full step and sub-step.

Among the six responses obtained by the GA, the best answer was the chromosome configuration sub-step B, with an energy consumption of 13.29 J, a displacement of 0,388 m, and relative energy of displacement of 34.25 J / m. Regarding heuristic walk, the ratio was decreased by 18%, and respect the chromosome configuration polynomial, the ratio decreased by 13.3%.

Another advantage of the approach with sub-step was the lowest time of calculation, compared with the method applying GA to full step.

VI. RECOMMENDATIONS

It is recommended a characterization of the AX-18 engine used in biped robot, which in this paper used the reference Mensink (2008) for the AX-12 engine [15].

It is also suggested to use genetic programming to increase the number of functions such as gait pattern generator, allowing to expand the solutions and not limit the known functions as polynomials and cosines, which were used in this work.

Future work may also use specialized software for 3D dynamic simulation with collision detector, such as: Adams, Ode, Redysim, among others; and include a dynamic walk.

It is recommended to use a physical controller and interact with software for reading sensors and feedback control implementation.

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