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Full Length Research Paper

Design of fuzzy algorithms locomotion for six legged walking robot

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One of the most relevant topics in the design of legged robots is to perform movements. The aim of this article is to present a set of algorithms that allow a six-legged walking robot to achieve the mobility of its different legs among irregular or no established actions, this gait is known as: free locomotion. The development of these algorithms using fuzzy logic allows the system to have a redundant behavior. The algorithms evaluation is performed by simulating the locomotion process of the robot.

Key words: Walking robot, free locomotion, margin stability, fuzzy logic, adaptive algorithm, predictive algorithm.

INTRODUCTION

How to move and decide the movement of different legs in a walking machine is one of the topics of greatest interest in the design of legged robots. The design of the algorithms for making decisions about which of the legs of the robot are removable and determine one move from all the possible actions defined on foot before walking through the environment (Arkin, 1998).

The locomotion of a six legged walking robot (hexapod) has been under research for many years (Liegeois, 1977). Zhiying et al. (2011) developed a concept to reproduce the natural walking of particular insects, having the problem of stability of the robot that needs to be solved. One popular gait for locomotion of a hexapod robot considers a strategy by fixed alternating tripods formed by triangles defined by the legs in contact with the terrain in most cases, the gravity center of the robot falls into a good stable conditions preventing the robot to fall. Due that the robot architecture is redundant, the control system development is highly complex, because the problem of stability of the robot is under a rigid cycled legs moves and robot’s body. The other side of the locomotion problem is to consider a non-rigid strategy which will be discussed in this article. We decide to extend the locomotion algorithms for quadruped walking robots developed some years ago (Vargas, 1994) for a kind of machine with more redundancy to improve stability, but also to take care of the models complexity for a robot with too many legs. After these considerations, we select a six legged robot design in order to propose and analyze the new algorithms.

The way to manage the free walking is an extremely complex task. The development of free locomotion algorithms for walking robots has been the subject of study and research for several years (Liegeois, 1977; McGhee et al., 1984). The problem has not yet been fully solved; it still requires further research to better understand the process of walking in this type of machine. In this way, we are motivated to create strategies with concepts and techniques of artificial intelligence that makes easier the free walking actions of this kind of machine (Philip et al., 2006).

In this paper, a free locomotion strategy is presented for research purposes. We define several concepts in order to facilitate the design of free locomotion gaits: Agent, environment, entry, reward and penalty. The hexapod robot as the agent, the environment is the place in which the robot moves (Kris et al., 2008). The entry (including signal booster) represents a collection signals

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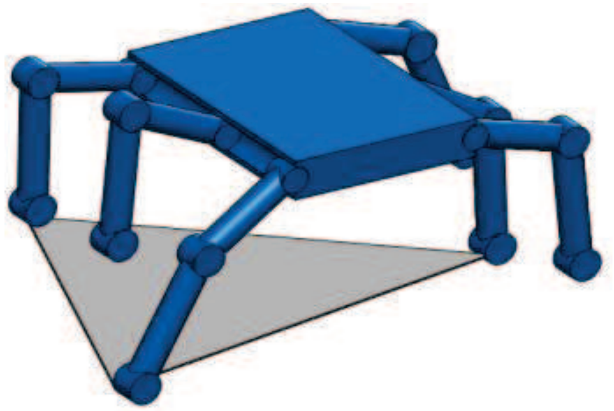

Figure 1. Six legged robot.

from the sensors used to evaluate the internal and external conditions of the hexapod (camera, contact sensor, encoders, etc.), the reward is a condition when the hexapod goes from one place to other place without any problem, and finally the penalty is the condition obtained when the robot has crashed during its locomotion.

In applications where the terrain is totally irregular and unknown, the use of wheeled mobile robot has a number of problems, mainly about vehicle stability and accessibility to certain parts. This is the type of applications were walking robots have better performance (Estremera and Gonzalez, 2002).

In real life, the land where the robot will move is unknown, and this is why it is important to develop knowledge and research (Bill and Joel, 2002).

In real life, the terrain where the robot will walk is unknown that is why we consider important to develop and research free locomotion for a hexapod. In this way, we hope to contribute for the development of this kind of robots and its applications, such as developed by Sony Co. Walking machine research help to understand the behavior of animal locomotion (Shaoping et al., 2001), considering that many of the characteristics of locomotion in these walking robots are based from observation of some animals.

ROBOT CONFIGURATION

In order to implement algorithms for locomotion of a walking robot, the first practical consideration is the morphology of the robot. The number of legs is the most important morphologist consideration (Solano et al., 2000), and in this particular case we will focus on the development of algorithms for a robot six-legged robot. The Figure 1 shows a six legged robot proposed by (Gorrostieta and Vargas, 2008).

There are several ways to organize the robot locomotion algorithm by following different criteria such as the stability margin, the path to follow, the best trajectory and the minimum criteria for energy. In this particular case we will focus on the stability margins as the main criterion for building the robot locomotion algorithm. To organize the proposed locomotion algorithm, it is considered the parameters in the fuzzy system development. The first consideration is the stability margin Sm which is an indicator of the robot stability. At the beginning of each joint movement the distribution of the legs on the surface of seven different areas labeled as A, B, C, D, E, F and G which is important part in the fuzzy system is taken into account. The supporting polygon is a parameter that is calculated before the stability margin and this is considered as a polygon projected to the surface where the robot moves and it is included the projection of the center of gravity of the robot.

In order to obtain the parameters concerning the mobility of the legs of the robot, firstly a vector is estimated which direction is the desired goal. On the other hand, it is also required a single vector of each of the legs which is labeled as Vp, then another vector is also calculated for each of the centers of the leg's workspaces in the desired direction, this is established as Vc.

Finally, we introduce a damping factor δ which helps to carry out the movements of the robot's legs smoother and on the other hand it does not reach the limits of motion in an abrupt way. In Table 1, the parameters used are grouped into four types, Stability Parameter, Geometric Parameter, Motion Parameter and Damping Parameter, considered their characteristics.

Figure 2 shows a geometric distribution of 7 areas determined by the imaginary lines formed between the 6 legs position of the robot legs and its intersection and the location of the projection of the robot gravity center. These proposals help to determine which legs have the opportunity to move without trading off the stability of the robot.

The geometric positions of each area, which are represented by coordinates in a R^2 plane, are described in the following Equations 1 to 23:

Area A

$$L1(x_1\, y_1), L2(\, y_2), Lil(x_{il}\, y_{il}) \tag{1}$$

$$x_{il} = \frac{(x_1 y_4 - x_4 y_1)(x_3 - x_2) - (x_2 y_3 - x_3 y_2)(x_4 - x_1)}{(y_2 - y_3)(x_4 - x_1) - (y_1 - y_4)(x_3 - x_2)} \tag{2}$$

$$yil = \frac{y_1 - y_4}{x_4 - x_1}\, xil - \frac{x_1 y_4 - x_4 y_1}{x_4 - x_1} \tag{3}$$

Area B

$$L2(x_2\, y_2), L4(x_4\, y_4), Lil(x_{il}\, y_{il}) \tag{4}$$

$$x_{il} = \frac{(x_1 y_4 - x_4 y_1)(x_3 - x_2) - (x_2 y_3 - x_3 y_2)(x_4 - x_1)}{(y_2 - y_3)(x_4 - x_1) - (y_1 - y_4)(x_3 - x_2)} \tag{5}$$

$$y_{il} = \frac{y_1 - y_4}{x_4 - x_1}\, x_{il} - \frac{x_1 y_4 - x_4 y_1}{x_4 - x_1} \tag{6}$$

Area C

$$L_1(x_1\, y_1), L_3(x_3\, y_3), L_{il}(x_{il}\, y_{il}) \tag{7}$$

Table 1. Parameters used in the fuzzy system.

Parameter type	Parameter
Stability parameter	The support polygon The center of gravity Stability margin, Sm
Geometric parameter	Areas labeled A, B, C, D, E, F and G Leg positions. The workspaces positions. $c_j(x_{cj}, y_{cj})$ $I_j(x_{Ij}, y_{Ij})$
Motion parameter	Vector address Motion vector of the leg, Vp Vector of the legs workspaces, Vc Magnitude of the displacement, dez
Damping parameter	Damping displacement, δ Damping exponential, γ

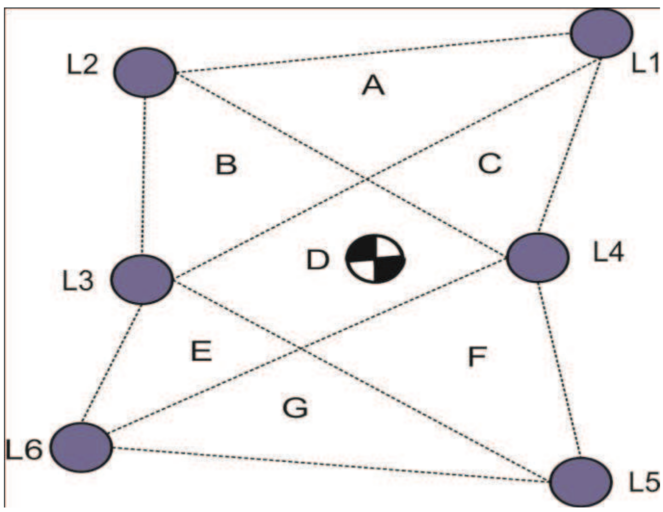

Figure 2. Seven distribution areas under the robot.

$$x_{il} = \frac{(x_1 y_4 - x_4 y_1)(x_3 - x_2) - (x_2 y_3 - x_3 y_2)(x_4 - x_1)}{(y_2 - y_3)(x_4 - x_1) - (y_1 - y_4)(x_3 - x_2)} \quad (8)$$

$$y_{il} = \frac{y_1 - y_4}{x_4 - x_1} x_{il} - \frac{x_1 y_4 - x_4 y_1}{x_4 - x_1} \quad (9)$$

Area D

$$L_4(x_4\ y_4), L_3(x_3\ y_3), L_{il}(x_{il}\ y_{il}), L_{i2}(x_{i2}\ y_{i2}) \quad (10)$$

$$x_{il} = \frac{(x_1 y_4 - x_4 y_1)(x_3 - x_2) - (x_2 y_3 - x_3 y_2)(x_4 - x_1)}{(y_2 - y_3)(x_4 - x_1) - (y_1 - y_4)(x_3 - x_2)} \quad (11)$$

$$yil = \frac{y_1 - y_4}{x_4 - x_1} xil - \frac{x_1 y_4 - x_4 y_1}{x_4 - x_1} \quad (12$$

$$x_{i2} = \frac{(x_3 y_6 - x_6 y_3)(x_5 - x_4) - (x_4 y_5 - x_5 y_4)(x_6 - x_3)}{(y_4 - y_5)(x_6 - x_3) - (y_3 - y_6)(x_5 - x_4)} \quad (13)$$

$$y_{i2} = \frac{y_3 - y_6}{x_6 - x_3} x_{il} - \frac{x_3 y_6 - x_6 y_3}{x_6 - x_3} \quad (14)$$

Area E

$$L6(x_6\ y_6), L4(x_4\ y_4), Li2(x_{i2}\ y_{i2}) \quad (15)$$

$$x_{i2} = \frac{(x_3 y_6 - x_6 y_3)(x_5 - x_4) - (x_4 y_5 - x_5 y_4)(x_6 - x_3)}{(y_4 - y_5)(x_6 - x_3) - (y_3 - y_6)(x_5 - x_4)} \quad (16)$$

$$y_{i2} = \frac{y_3 - y_6}{x_6 - x_3} x_{il} - \frac{x_3 y_6 - x_6 y_3}{x_6 - x_3} \quad (17)$$

Area F

$$L5(x_5\ y_5), L3(x_3\ y_3), Li2(x_{i2}\ y_{i2}) \quad (18)$$

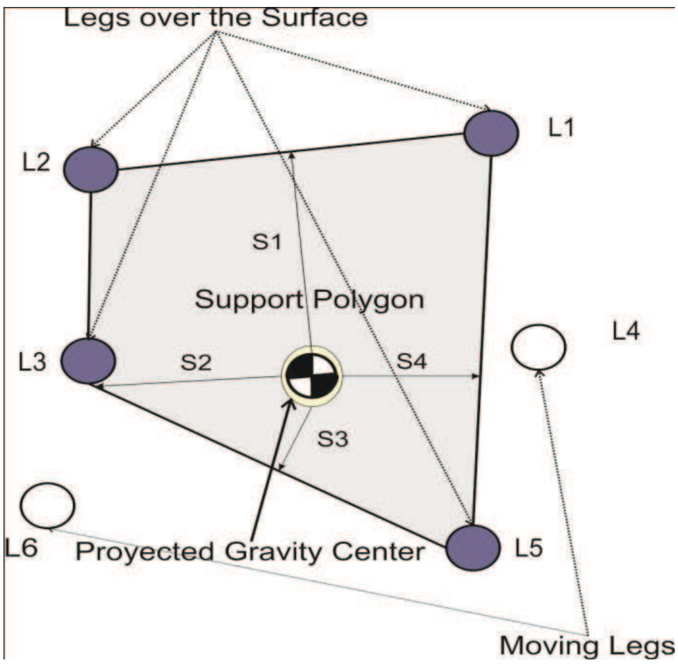

Figure 3. Diagram of six legged robot and the projection of gravity center.

$$x_{i2} = \frac{(x_3 y_6 - x_6 y_3)(x_5 - x_4) - (x_4 y_5 - x_5 y_4)(x_6 - x_3)}{(y_4 - y_5)(x_6 - x_3) - (y_3 - y_6)(x_5 - x_4)} \quad (19)$$

$$y_{i2} = \frac{y_3 - y_6}{x_6 - x_3} x_{il} - \frac{x_3 y_6 - x_6 y_3}{x_6 - x_3} \quad (20)$$

Area G

$$L5(x_5\, y_5), L6(x_6\, y_6), Li2(x_{i2}\, y_{i2}) \quad (21)$$

$$x_{i2} = \frac{(x_3 y_6 - x_6 y_3)(x_5 - x_4) - (x_4 y_5 - x_5 y_4)(x_6 - x_3)}{(y_4 - y_5)(x_6 - x_3) - (y_3 - y_6)(x_5 - x_4)} \quad (22)$$

$$y_{i2} = \frac{y_3 - y_6}{x_6 - x_3} x_{il} - \frac{x_3 y_6 - x_6 y_3}{x_6 - x_3} \quad (23)$$

STABILITY MARGIN

Another parameter in the construction of the algorithm is called the support polygon which is determined by the polygon projected on an imaginary plane on a surface where the legs are supported, in Figure 1 is shown a triangle for this polygon.

Once calculated and found the robot's center of gravity, it is projected onto the movement surface plane, next, should be analyzed the conditions under which the robot has presented a stability. To consider this effect use the *Sm* stability margin, can determine the degree of stability of the robot and is defined as the minimum distance between the projection of the center of gravity within a safety margin and the border that exists in each of the sides of the support polygon generated in the current state of the robot. Figure 3 shows the location of each vector of calculated projection of the center of gravity perpendicular to the boundary of the support circle. Equation 24 defines the calculation of the stability margin.

$$Sm = \min(S1, S2, S3, S4, S5, S6) \quad (24)$$

By studying these models and the mechanical constraints of the robot, it was determined that the workspaces vary the height of the robot body with respect to the surface. If the surface is closer to the robot's body we shared workspaces as you move away and you have exclusive workspace due to the configuration of the robot (Shaoping et al., 2001). In Equation 25, it is shown the relationships that allow us to locate each of the points in Cartesian space with respect to the angles.

$$p_j = \begin{bmatrix} x_{Lj} \\ y_{Lj} \\ z_{Lj} \end{bmatrix} = \begin{bmatrix} (l_2 sin\theta_2 + l_3 cos\theta_3) cos\theta_1 \\ (l_2 sin\theta_2 + l_3 cos\theta_3) sin\,\theta_1 \\ l_2 sin\theta_2 + l_3 cos\theta_3 \end{bmatrix} \quad (25)$$

Where L_2 and L_3 is the length of the link, being θ_1, θ_2, θ_3 the orientation of the links that form each of the legs of the robot respectively. The proposed values for the development of the trajectory of each leg is proposed by Ilg et al. (1999), where a movement study of a mammal was presented.

One of the main parameters of the robot motion is the desired direction. This direction is determined by the browser, previously evaluated the task, goal, or type of obstacles that stand in the way of the robot. The first calculation was the direction vector that is generated from the center of gravity *CG (xg, yg, zg)* to the destination. From this vector, a unit vector is obtained, which gives meaning and direction to each of the legs.

To determine the limits of movement of each of the legs the location of each of the legs inside your workspace must be known and as well as the different possibilities of movement in this space. Therefore, if you know a vector that allows us to know the direction of this movement V_1, V_2, V_3, V_4, V_5 and V_6, you can also restrict the movement of the many possibilities within the workspace. The peak shift is obtained at the intersection of the direction vector of each leg with the edge of the workspace of the leg that will perform the movement.

Figure 4 shows the location of the legs within the workspace, as well as illustrates the geometric centers of each of them represented in the Equation 26. To determine the movement a direction vector was considered, calculated from the current position of the leg, the vector of the geometric center and the intercept with the boundary of the workspace, determining I. View the coordinates in Equation 26.

$$c_j(x_{cj}, y_{cj}) \qquad I_j(x_{Ij}, y_{Ij}) \qquad with\ \ j = 1,2,3,4,5,6 \quad (26)$$

As shown in Figure 4, the vector formed from the geometric center to the destination, is denoted by *Vc* and the corresponding leg number. This vector intersects the boundary of the workspace; it is precisely at that point where we consider the endpoint of the leg movement. Equation 27 shows the vectors of the legs. The movement of each leg is described by the vector Vp and the number of leg motion, represented in Equation 27.

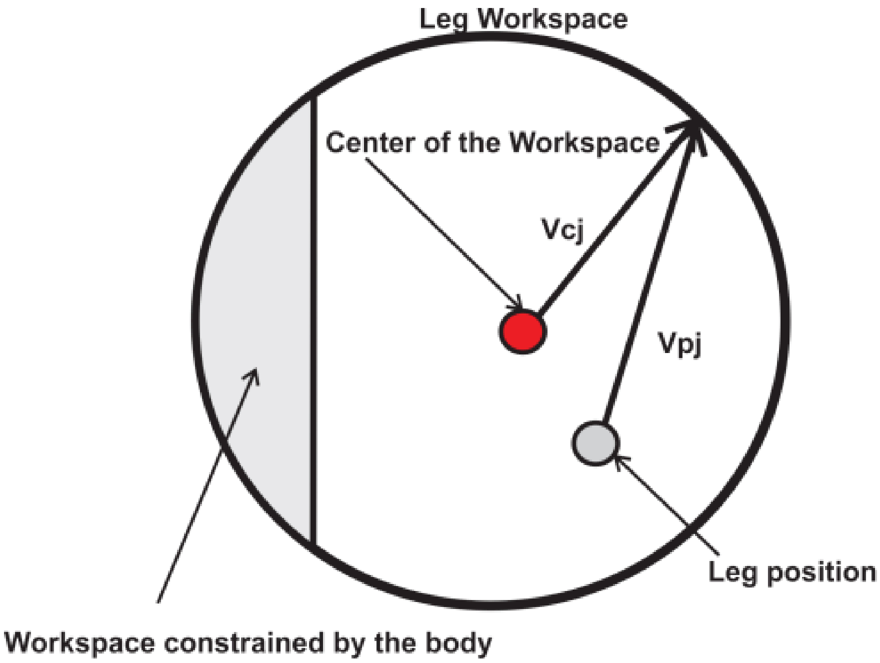

Figure 4. Movement vectors over the workspace.

$$\overrightarrow{Vc_j} = (x_{ij} - x_{cj})\hat{\imath} + (y_{ij} - y_{cj})\hat{\jmath} \quad \overrightarrow{Vp_j} = (x_{ij} - x_j)\hat{\imath} + (y_{ij} - y_j)\hat{\jmath} \quad j = 1,2,3,4,5,6 \qquad (27)$$

The displacement magnitude of the joint was calculated from the distance of each leg to the point I as in Equation 28. This offset value can be modified by a variable so that the movement of the leg is limited and not always move to the edge of the workspace.

$$dez_j = \delta\sqrt{(x_{ij} - x_j)^2 + (y_{ij} - y_j)^2} \quad j = 1,2,3,4,5,6 \qquad (28)$$

The δ calculation as shown in Equation 29 is an exponential decay.

$$\delta_j = e^{-\gamma_j} \quad j = 1,2,3,4,5,6 \qquad (29)$$

The γ exponential power of an initial position in this vector is initialized to zero, and then goes to determine the value of each of these values as the distance from the step to be executed.

LOCOMOTION FUZZY ALGORITHM

The goal of the robot locomotion algorithm is to generate the robot's movements in order to bound a destination point. We have two types of locomotion, which can be developed by a set of movements and determined actions. The other way is called free locomotion, and this kind of the robot locomotion will perform a movement or action depending on several external factors, and depend on the environment. In the case of six-legged robot the locomotion is performance using a three-legged support, thus creating a triangle as a polygon of support and most models in case the projected center of gravity creates a very margin stability.

In the locomotion algorithm case, free movement of the legs of a hexapod robot can go from one leg to three of them, the decision-making is complicated and could again dependent on several factors. In the development of the Fuzzy algorithm, it is the application of three basic membership functions firstly considered and as a result it was decided to use the triangle for simplicity and calculation parameters. In addition, to facilitate the adaptation process, which turned out to be very similar to the Gaussian function, the main inconvenience is the implementation on different platforms. Then, the application turned out to be more convenient to calculate the slopes of the triangular membership functions, as previously mentioned.

For the fuzzy logic system, a Mandami type is considered in (30) by (Tanaka, 1997).

$$R_n: If\ L_i\ is\ B_i^n(l_i)\ and \ldots and\ L_i\ is\ B_i^n(l_i)\ then\ y_i is\ S_i^n(y_i) \qquad (30)$$

Where R_n denotes the nth rule, , $x = (x_i, \ldots, x_m) \in X \subset \mathbb{R}^n$

and inputs variable, control variable and $B_i^n(x_i)$ are defined as:

$$B_i^n(x_i) = \begin{cases} \dfrac{x-a}{b-a} & a \le x \le b \\ 0 & if\ x < a\ and\ x > c \\ \dfrac{c-x}{c-b} & b \le x \le c \end{cases} \qquad (31)$$

Figure 5 shows the membership functions possible to apply the fuzzy algorithm, the first is when we have a low mobility of the leg, the second half when we have mobility, and the third when we have high mobility.

In Equations 32, 33 and 34, Berkan (1996) present the representation of these functions, where the membership function is denoted by $B_i^n(x_i)$ and and *dn* is the distance calculated in the

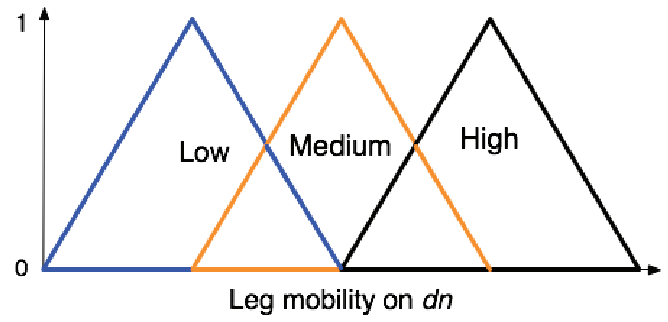

Figure 5. Fuzzy membership functions.

motion vector if the universe of *D* is the maximum distance at which you can move the leg. In the present situation this value can vary according to conditions of workspace in each of the legs.

$$Low = \{(dn, B^{L}_{dni}(dn))\} \qquad dn \in D \tag{32}$$

$$Medium = \{(dn, B^{M}_{dni}(dn))\} \qquad dn \in D \tag{33}$$

$$High = \{(dn, B^{H}_{dni}(dn))\} \qquad dn \in D \tag{34}$$

This paper proposes the development of each of the legs to a definite point. This progress is defined by the intersection of the vector address located in the leg and the workspace of the leg as shown in the previous section. The second variable to consider is the stability margin which can be defined in a similar way as in the mobility of the legs.

$$Low = \{(Sm, B^{L}_{Smi}(Sm))\} \qquad dn \in S \tag{35}$$

$$Medium = \{(Sm, B^{M}_{Smi}(Sm))\} \qquad dn \in S \tag{36}$$

$$High = \{(Sm, B^{H}_{Smi}(Sm))\} \qquad dn \in S \tag{37}$$

Where the membership function is denoted by $B^{n}_{i}(Sm)$ and *Sm* is the stability margin in the motion and the universe of S is the maximum distance the support polygon.

It is necessary to consider that the membership functions $B^{n}_{i}(dn)$, vary depending on the characteristics of each leg. In the study, they were divided into three groups to determine the membership function, the legs *L1* and *L2* have the same work space for the robot's physical characteristics, it is so defined the membership function for the low mobility of this pair of $B^{L}_{dni}(dn)$ legs as high mobility and will $B^{H}_{dni}(dn)$. Similarly to the legs, is determined by *L2* and *L3* the environment and the *L6* and *L5* on the real of the robot.

Fuzzy inference rules are expressed in terms of input variables to the fuzzy system and are playing the biggest role in making decision. These are drawn from the experience of the expert as is known in the language of fuzzy logic or heuristic methods. In the case of free locomotion algorithm for the movement of one leg exit opportunities are six.

$$R_n: If\ Sr\ is\ B^{n}_{Smi}(Sm)\ and\ L_1\ is\ B^{n}_{dni}(dn) and\ \dots\ L_6\ is\ B^{n}_{i}(dn)\ then\ p_i is\ S^{n}_{i}(ds) \tag{38}$$

$$Little = \{(ds, B^{L}_{dni}(ds))\} \qquad dn \in D \tag{39}$$

$$Much = \{(ds, B^{M}_{dni}(ds))\} \qquad dn \in D \tag{40}$$

$$S^{n}_{i}(ds) = L_1\ is\ B^{n}_{dsi}(ds) and\ L_2\ is\ B^{n}_{dsi}(ds) \dots\ L_6\ is\ B^{n}_{dsi}(ds) \tag{41}$$

In this system, the critical point occurs when there are multiple outputs with the same chance of a result for the algorithm. In this case, using a modification of the membership function, which is known as alpha-cut and the main purpose of these amendments is to give weight to the membership function as data entry, so that obtain a single output of a redundant system as presented. That is, if we output the motion of three legs for example, then you must decide which of these is to be moved.

$$A^{\alpha} = \{dn \mid \mu(d) < \alpha\} \tag{42}$$

$$\mu_A(d) = \vee[\alpha \bullet \mu_{A\alpha}(d)] \quad d \in D \tag{43}$$

It's very similar to what happens when we start a walk and either foot has the same chance of taking this first step. This occurs in the algorithm but with the difference that you have six chances. For this condition, we introduced a random variable which gives weight to the new role belonged to the alpha cut, which is also referred to as a certain threshold belonged, denoted by the Equation 44 and 45 (Berkan, 1996).

$$A^{\propto} = \{dn\ \vdots\ B^{n}_{i}(dn) < \propto\} \tag{44}$$

$$B^{n}_{A}(dn) = \forall[\propto \cdot B^{n}_{A^{\propto}}(dn)] \tag{45}$$

In the shown algorithm it was necessary to adjust the rules of inference. Specifically, the member functions. The workspaces characteristics introduce a variation, since the conditions of these areas change with respect to the position of the robot in the coordinate axis z, which is why the definition of membership functions will change to know how big mobility or how small it is. Due that the surface topography, the conditions of the leg mobility is changing according with the work space.

For this reason it is considered an adjustment to the membership functions that adapt to these changes, as stated the general equation of a fuzzy system.

The decisions that were scheduled in the algorithms are quite similar to a person who has no favorable equilibrium conditions. In this case the algorithms make smooth and short movements, if the conditions of stability are not good low category of fuzzy functions are evaluated, then this state presents moves only in one leg of the

Table 2. Values of the robot's movements.

Step	NL	Sm	L1	L2	L3	L4	L5	L6
1	3	0.0760	0.0964	0.00	0.00	0.1000	0.1420	0.00
2	2	0.0405	0.00	0.0852	0.00	0.00	0.00	0.3252
3	3	0.0778	0.0757	0.00	0.00	0.0757	0.0811	0.00
4	1	0.0294	0.00	0.00	0.1493	0.00	0.00	0.00
5	2	0.0395	0.00	0.1635	0.00	0.00	0.00	0.1635
6	3	0.0909	0.1308	0.00	0.00	0.1308	0.1308	0.00
7	1	0.0550	0.00	0.00	0.1477	0.00	0.00	0.00
8	2	0.0462	0.00	0.1320	0.00	0.00	0.00	0.1320
9	3	0.0925	0.1337	0.00	0.00	0.1337	0.1337	0.00
10	3	0.0745	0.0398	0.0593	0.1467	0.00	0.00	0.00
11	2	0.0525	0.00	0.0751	0.00	0.00	0.1149	0.00
12	3	0.0920	0.0958	0.0207	0.0879	0.00	0.00	0.00
13	1	0.0911	0.00	0.00	0.00	0.1587	0.00	0.00
14	2	0.0455	0.1079	0.00	0.00	0.00	0.00	0.2630
15	3	0.0807	0.0335	0.1414	0.1483	0.00	0.00	0.00
16	1	0.0849	0.00	0.00	0.00	0.1477	0.00	0.00
17	2	0.0429	0.00	0.1143	0.00	0.00	0.2764	0.00
18	3	0.0776	0.1480	0.0337	0.1491	0.00	0.00	0.00
19	1	0.0840	0.00	0.00	0.00	0.1472	0.00	0.00
20	2	0.0595	0.0938	0.00	0.00	0.00	0.00	0.2753
21	3	0.0701	0.0465	0.1403	0.1476	0.00	0.00	0.00
22	1	0.0823	0.00	0.00	0.00	0.1404	0.00	0.00
23	2	0.0385	0.1143	0.1143	0.00	0.00	0.00	0.00
24	3	0.0778	0.0331	0.0331	0.1427	0.00	0.00	0.00
25	1	0.0915	0.00	0.00	0.00	0.00	0.3368	0.00

robot. In other state, if the conditions of stability are regular medium, then the robot can move two legs. In the case when the robot has very good stability conditions it will dare to move three legs.

RESULTS

To test the proposed algorithms and determine the robot trajectory we analyze stability margin in the first part of this study by doing 25 steps. Table 2 shows the results obtained when legs project different conditions for the stability margin.

Figure 6 shows the behavior of the stability margin, according with the fuzzy functions, the algorithms tries to maintain an oscillatory condition to redefine stability in each step. In all cases there is a window of stability within the polygon does support is that despite movements occur in the graph does not compromise the stability of robot. Values are analyzed by simulating the kinematics of the robot (Gorrostieta and Vargas, 2008).

Another performance of the algorithms is to use the fuzzy functions algorithms in similar routes and simulate walking strategies several times. Figure 7 shows the performance and the behavior of stability margin. We analyze the values of the stability margin, because its differences are caused due to the movements of the robot also are quite different even though it was the same route. It is important to note that the algorithms work freely, in other words there is not a planned gait strategy before to evaluate the locomotion.

DISCUSSION

Simulations of fuzzy algorithms are presented. The results show how the robot can walk keeping stability. The strategy designed is based in the method of working areas, that is shown in the first section of this work and which allows the algorithm to take each of the decisions. The fuzzy system used in this work, present how the adaptation according with the changes on the surface conditions.

It would be interesting to consider another method of decision-making, could be more natural perhaps using neural networks that provide a response more attached to the natural movements of insects or mammals.

Another proposal would use the neuromechanical of moving and to study the mechanism of movement, and perhaps could use a neural network with specific features for this task.

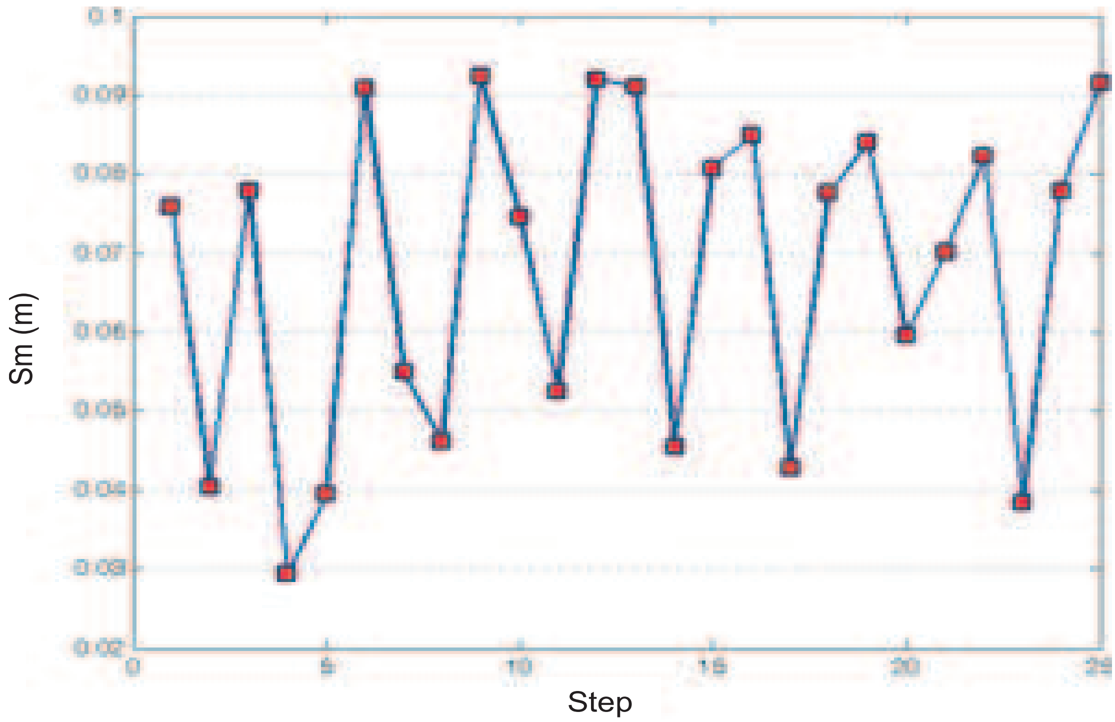

Figure 6. Behavior of stability margin.

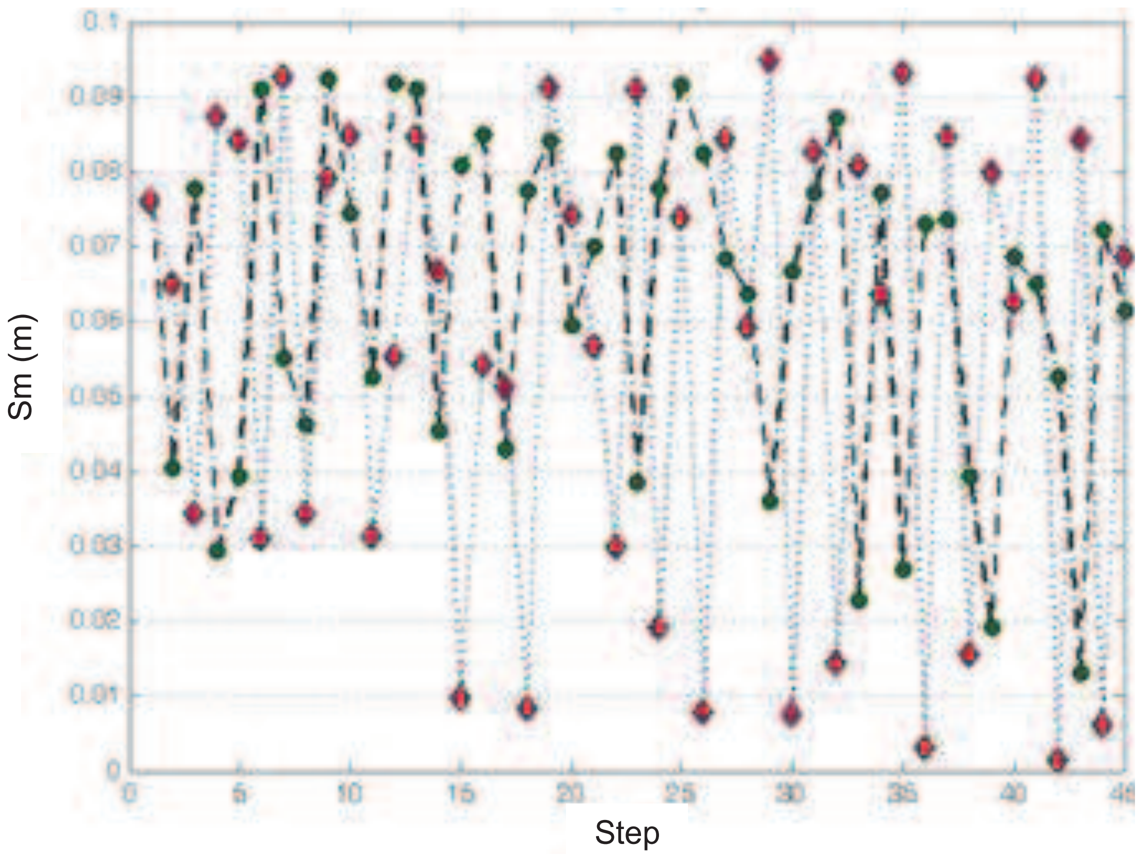

Figure 7. Behavior of stability margin.

Conclusions

The presented locomotion algorithms solved with a number of movements of the robot if one has a planned earlier movements which is known as free locomotion, the criteria presented in the development of algorithms was the areas, the margin of stability and support different polygons that appeared in each of the motions proposed. As could be observed, the stability margin or along a path to follow this is always looking for a high value that allows the robot to have more possibilities of movement without compromising their stability or this fall.

A method to ensure convergence of the movements was exposed in section 3, which calculates the intersection of the motion vector for each leg, with the motion vector of its work space geometric center. In this way, the method proposed in this paper avoid the non-linearity models of the robot, by applying particular concepts and techniques of artificial intelligence to build a fast decision in the locomotion process. On the other side, we consider as the walking process is a task with no higher performance, cause the global position of the robot's body can be adapted according with the moves of the legs. Under this consideration, the algorithms don't require a high computational cost to be implemented. For future work, we are motivated to improve and optimize the fuzzy system in order analyze decisions for more complex tasks, like obstacle avoidance.

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