Free Locomotion for Six Legged Robot

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Abstract: - In the present article the fuzzy algorithm for free locomotion is developed, which permits a six legged walking robot to accomplish a movement according its actual situation. In this case, the robot does not have set actions and pre-determined movements, which is known as free locomotion. One of the parameters considered in the algorithm is the stability margin of the robot. The development of these algorithms utilizes fuzzy logic techniques for the locomotion and terrain adaptability. The valorization of the results is accomplished through the simulation of the robot.

Key-Words: - Walking robot, Free locomotion, Stability margin, Fuzzy algorithm, Simulator.

1 Introduction

In the applications where the surface is completely irregular and unknown the use of robots with wheels presents an unlimited number of problems, one of which is the stability of the vehicle and the accessibility of certain places. In this type of application the use of walking robots provides better results.

Considering the surroundings, it is built with the anthropomorphic characteristics of a natural walking biped: like the human being. Analyzing the majority of the constructions, they are designed so that this potent walking being is able to move from one place to another. This type of environment is so marked that people who use wheel chairs require special constructions in order to share the space. All of the above leads to research and development of walking machines for various applications such as commercial, industrial, or entertainment [1]. The research of walking machines attempts to explain somewhat animal locomotion [2]. Keeping in mind that many of the characteristics of locomotion of these types of walking machines are based on observations of animals.

2 Locomotion

For the development of the locomotion systems it is necessary to take into account the following aspects:

Avoid allowing the robot to loose its equilibrium. This is accomplished by observing the location of the center of gravity between the legs which support the body when it moves.

The distribution of the load supported by the robot on each of its legs is important to consider.

To find an adequate place to support the robot's leg. This does not present any difficulty on flat surfaces, but it becomes more complicated on irregular terrain.

This work presents the development of the free locomotion algorithm in a six legged robot, which permits the robot to move each of its legs.

3 Robot Stability

The stability of the robot is one of the important characteristics in the development of locomotion. In this research this quality is used to find the behavior of a robot in a determined trajectory and in deciding how many and which legs to move.

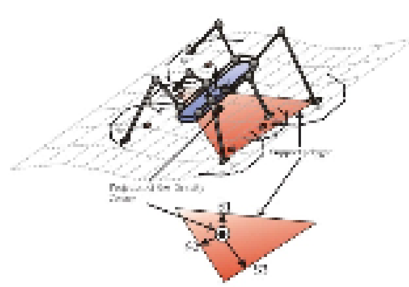

Fig. 1 Support polygon.

The robot which is being studied has six legs. In this case it has a similar topology to an ant; this is developed in [3]. For the stability of the robot it is considered that it must have a minimum of three legs, which form a triangle to support the robot., when it is supported by four legs it forms a four sided polygon. five sides are formed when the robot is supported by five legs. The center of gravity must be included inside of the support polygon, independent of the number of legs which come in contact with the surface. The essential condition to keep the robot from falling us was analyzed in [4]. The polygon formed by the legs in the surface is know like support polygon. In this case it is polygon can be formed of three sides up to six sides when the six legs are in contact on surface.

The support polygon is used in the process of locomotion, as the definition of the support polygon under static condition is calculated, despite this parameter is used in movement functions. This is possible to consider that a support polygon does not change during moment, in which the legs arrive previously at a space within work space predetermined by the algorithm locomotion.

As a measurement of stability in the walking machine it's stability margin is considered. The stability margin is shown in the Equation 1; it is the shorter of the distances from the vertical projection of the center of gravity to the boundaries of the support polygon.

$$Sm = \min(S1, S2, S3, S4, S5, S6) \quad (1)$$

4 Free Locomotion

In order to begin the free locomotion algorithm design to apply in a robot, one area of work must be divided into seven areas that are formed by the intersection on the lines which are formed between the legs; as shown in Fig 2. Each area is label with a letter. This technique was implemented in the free locomotion algorithm robot of four legs; like development in [5]. In this research, this technique is used.

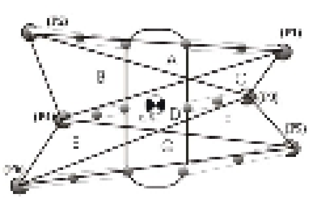

Fig. 2 Area proposes in the walking robot.

In Table 1 the different possibility of movement for only one leg is presented. It's considered that the center of gravity is on one of the seven different areas defined in Fig 2.

Area	Mobility leg
A	P3 P4 P5 P6
B	P3 P4 P5 P6
C	P3 P4 P5 P6
D	P1 P2 P3 P4 P5 P6
E	P1 P2 P3 P4
F	P1 P2 P3 P4
G	P1 P2 P3 P4

Table 1 Mobility of one leg

When one leg is lifted. the robot has one support polygon of five sides, in witch the center of gravity is projected on the surface. which must be included in one of the determinate area to assured that robot stability.

Area	Mobility of two legs
A	P1-P5 P1-P6 P3-P6 P4-P5
B	P3-P4 P3-P5 P4-P5 P4-P6 P5-P6
C	P2-P5 P2-P6 P3-P6 P4-P6 P5-P6
D	P1-P5 P1-P6 P2-P5 P2-P6 P3-P4
E	P1-P2 P1-P3 P1-P5 P2-P5 P3-P4
F	P1-P2 P1-P4 P1-P3 P2-P3 P3-P4
G	P1-P2 P1-P6 P2-P4 P2-P6 P3-P4

Table 2 Mobility of two legs

In Table 2, the different possibility of movement for two legs is shown. In this case the support polygon has four sides, where inside this area. the center of gravity is included.

Area	Mobility of three legs
A	P1-P4-P5 P1-P5-P6 P3-P4-P6 P3-P5-P6
B	P3-P4-P5 P3-P4-P6 P3-P5-P6 P4-P5-P6
C	P2-P3-P6 P4-P5-P6 P2-P5-P6 P3-P4-P6
D	P1-P4-P5 P3-P5-P6
E	P1-P2-P3 P1-P4-P5 P1-P2-P5 P1-P4-P3
F	P1-P2-P4 P1-P4-P3 P1-P2-P3 P2-P4-P3
G	P1-P2-P4 P1-P2-P6 P2-P5-P3 P2-P3-P4

Table 3 Mobility of three legs.

In table 3, the different possibility of movement for three legs is shown. In this case the support polygon is a triangle, this way the minimum possibility of the robot stability is had.

Another parameter to consider in the algorithm is the leg mobility that each one has. This is providing the work space corresponding, which are defined by the Equation 2 evolution in the space coordinate x,y,z.

$$\begin{aligned} x &= (l_2\cos\theta_2 + l_3\cos\theta_3)\cos\theta_1 \\ y &= (l_2\cos\theta_2 + l_3\cos\theta_3)\sin\theta_1 \\ z &= l_2\sin\theta_2 - l_3\sin\theta_3 \end{aligned} \tag{2}$$

The variables and parameters that built the mathematical model of the leg robot are the following: θ_1, θ_2, θ_3 are the relative angles between the links, which are independent; l_2 and l_3 are the effective longitude for the link 2 and link 3. This model was developed in [6].

The work space changes depending on the position of the robot body with respect to the surface, if it is near to the robot body then there are work spaces shared, otherwize the work space is independent. This robot configuration permits this type of work space behavior.

The location of the legs inside the work space is shown in Fig. 3, Also the geometric center of each leg can be seen. The mobility of each leg is determined by the direction and the present leg position, the vector of the geometric center of the work space and the interception direction vector with the limit of the work space.

The vector direction for each leg is presented in Equation 3, the result is computed and the direction of the robot's legs advance as Fig 3 can be seen.

$$Vd = (Vp1 \quad Vp2 \quad Vp3 \quad Vp4 \quad Vp5 \quad Vp6) \tag{3}$$

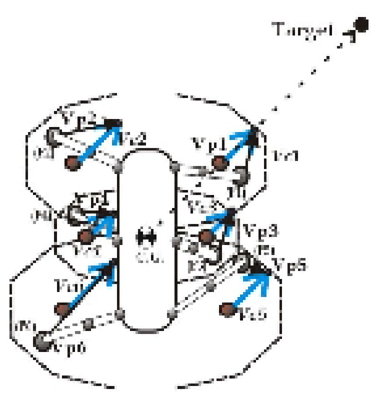

Fig. 3 Advance Vector of legs.

The magnitude of the leg displacement is calculated from the distances of each leg: as it is in Equation 4 for three of the legs in R^2 like example. This displacement value can be modified by the δ such as the movement of the leg is limited and not always do the legs move to their work space limit.

$$\begin{aligned} d\varepsilon z_1 &= \delta_1\sqrt{(x_{i1}-x_1)^2+(y_{i1}-y_1)^2} \\ d\varepsilon z_2 &= \delta_2\sqrt{(x_{i2}-x_2)^2+(y_{i2}-y_2)^2} \\ d\varepsilon z_3 &= \delta_3\sqrt{(x_{i3}-x_3)^2+(y_{i3}-y_3)^2} \end{aligned} \tag{4}$$

The parameter δ is determinate in the Ec 5, which is an exponential decrease.

$$\delta = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} = \begin{bmatrix} e^{-\gamma_1} \\ e^{-\gamma_2} \\ e^{-\gamma_3} \\ e^{-\gamma_4} \\ e^{-\gamma_5} \\ e^{-\gamma_6} \end{bmatrix} \tag{5}$$

The power of the exponent γ, is ordered in the corresponding vector, as shown in Equation 6, the first value of the vector must be initialized in zeros, later in the algorithm this value can be changed according to the distances of the desired step.

$$\gamma = [\gamma_1 \quad \gamma_2 \quad \gamma_3 \quad \gamma_4 \quad \gamma_5 \quad \gamma_6] \tag{6}$$

Another form to determine the distances value of each leg is the previous calculation; it is done by the algorithm.

5 Fuzzy System

The first parameters that are considered in the development of the locomotion algorithm are the mobility of each leg. In this case, an adaptation system is required. This system is integrated in the development of the fuzzy algorithm. This fuzzy system needs to change the value in the membership function according with the variation space work. This variation is caused by irregular terrain.

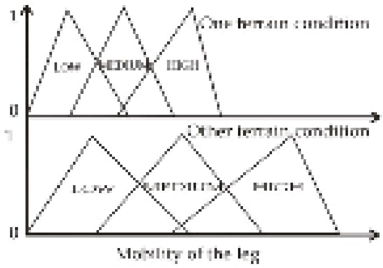

Fig. 4 Fuzzy memberships function.

The fuzzy membership functions apply in the algorithm is shown Fig 4. The first case is presented when the leg mobility is low, the second when the mobility leg is medium and the last when there is high mobility. In the Equations 7, 8 and 9 the fuzzy membership function is denoted $\mu(d)$ and dn is the computed range in the movement vector. In this case the universe of D considers the maximum distance to which the leg can be moved. For that present situation this value can vary according to conditions of work space.

$$A1 = \{(dn, \mu_B(dn, \zeta))\} \quad dn \in D \qquad (7)$$

$$A2 = \{(dn, \mu_M(dn, \zeta))\} \quad dn \in D \qquad (8)$$

$$A3 = \{(dn, \mu_A(dn, \zeta))\} \quad dn \in D \qquad (9)$$

Where ζ is the value to use in the fuzzy membership function, this value must be change with different terrain.

In this fuzzy algorithm the robot makes a decision about what number of legs will move. There are four movement possibilities: one leg, two legs, three legs and the body.

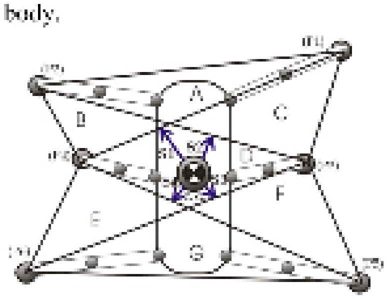

Fig. 5 Stability margin inside one of seven areas.

In algorithm development, there are two different ways to calculate the stability margin: one is required before the fuzzy algorithm, shown in Fig 7. The other is required after the algorithm, where this last value is used to know the locomotion performance.

The first stability margin is used to decide whichever legs will move in the next step and this way determine the future robot displacement. The calculation for stability margin is the minimum distances from the center of gravity to the boundaries of the area where it is, as can be seen in the Fig. 5. This variant of the calculation of the stability margin will allow the robot to have information before arriving to decision algorithm.

The fuzzy algorithms outputs will allow it to move between one or three legs and the robots body, this depends on the different condition of the input and the present robot stability. This required to introduce the fuzzy algorithm another membership function for the stability margin. In Fig 6 the membership functions is shown.

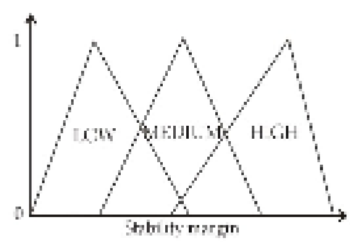

Fig. 6 Fuzzy memberships function for the stability margin.

In the Equations 10, 11 and 12 the fuzzy memberships functions for the stability margin are represented, where Sm' is the stability margin calculated and S is the universe, in this case this value is constant.

$$Sb = \{(Sm', \mu_B(Sm'))\} \quad Sm' \in S \qquad (10)$$

$$Sme = \{(Sm', \mu_M(Sm'))\} \quad Sm' \in S \qquad (11)$$

$$Sa = \{(Sm', \mu_A(Sm'))\} \quad Sm' \in S \qquad (12)$$

The fuzzy inference rules use in their consequents one or more output variable, the tables 1, 2 and 3 give this output.

The decision made is very similarly when talking about a person's sense of balance. For example: if the person's balance is not very stable, then the movement of the leg will be smooth and short; that is to say that there is a possibility to fall. In the fuzzy algorithms there is the condition of low stability in which the robot will move only one leg. For the cases on medium stability condition the robot will move two legs, and the last if the robot has very good stability condition then it will move three legs.

In this system, the important point is presented when there are several outputs with the same input variables. In this case the membership function must be changed. The alpha cut is proposed in Equation 13 and the main objective for this modification is to give one different weight to membership functions, shown in Equation 14. Therefore the algorithm has a single output. It is proposed to resolve the redundancy of the system.

$$A^{\alpha} = \{d \mid \mu_A(d) \geq \alpha\} \qquad (13)$$

$$\mu_A(d) = \vee\left[\alpha * \mu_{A^\alpha}(d)\right] \quad d \in D \qquad (14)$$

The cut α is determined by a random generator like the ith value of x_i.

$$\alpha = x_i \bmod 2 \quad i = 1,2,\ldots,n \qquad (15)$$

The alpha cut and the ξ built an adaptive fuzzy system. It will change the membership function according to the situation present where the robot is walking.

The algorithm of the free locomotion is shown in Fig. 7. In the last part, one predictor is included. The objective of this part of the algorithm became an extrapolation to the future about the next step that the robot could execute. This way the robot can know the next stability margin when certain movements are executed.

The main purpose of the predictor stage is to improve good stability in the robot. This means it has a better stability margin. There are two algorithms of locomotion: the first does not make any prediction, it only take the present stability margin and makes the decision about which legs can be move in the next step. The second has more instruction programs that make it possible to know the movement of the leg it will execute; this way the stability is better analyzed and the leg movement is executed.

In case that the algorithm does not find a solution in the leg movements, the robot could move the body and this way the condition of mobility will be changed. If the terrain conditions are not appropriate, then the robot will change the position of it's legs.

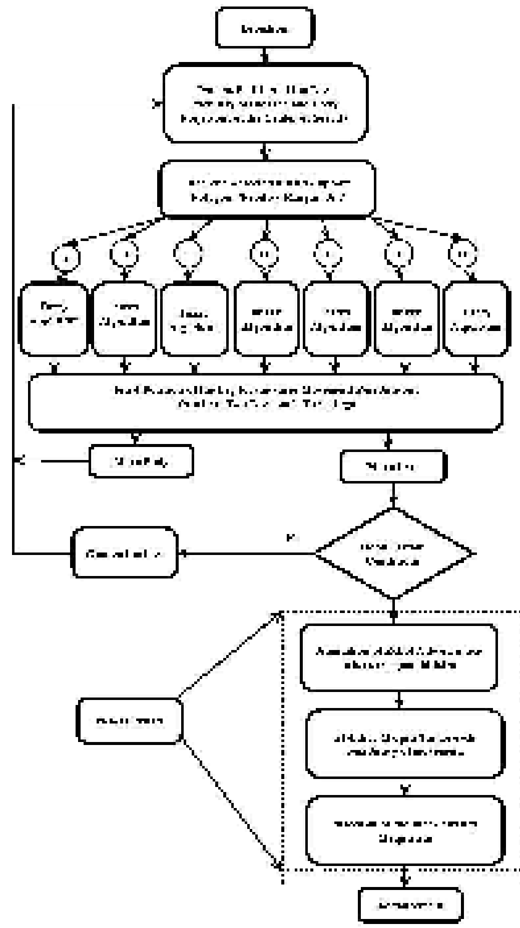

Fig. 7 Free Locomotion Algorithm.

6 Resultants of the Algorithm

The functionality of the algorithms was proved in two robot simulators developed with this purpose in which specific trajectory and terrain conditions were selected.

The comparison parameter which was taken as indicating of the algorithms performance was the stability margin. In Fig 8 appears the result of the algorithms. The stability margin in the both algorithms can be seen. This specific trajectory can be observed in free locomotion algorithm with prediction, the stability margin tries to maintain a high value. Also the algorithm without prediction has a good performance but with a low stability margin.

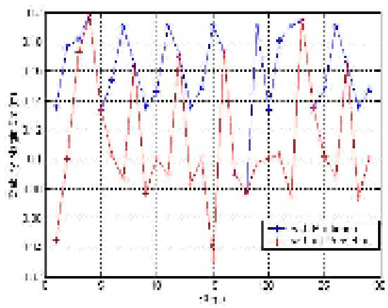

Fig.8 Stability margin.

The movement equations are programmed into the Simulator. It computes the relative position of the robot's leg with respect to the center of gravity and it's projection in the support polygon. The Simulator has the configuration of the robot under different points of view and terrain condition. This result can be shown when the geometry and the stability of the robot is walking on different types of terrain. In Fig. 9, one view of the six leg robot is presented.

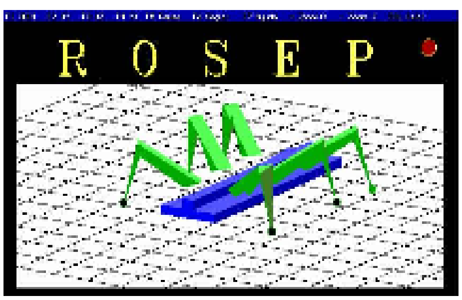

Fig. 9 Six leg Robot Simulator.

In Fig. 10, the robot simulator is presented. It has the similar topology to that of an ant. The algorithms were inserted into both simulators, then the behavior and evolution of the robot can be evaluated.

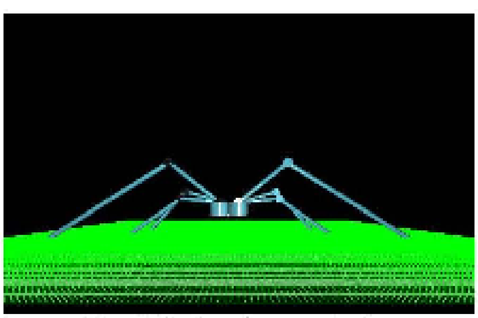

Fig. 10 Six leg robot ants simulator.

7 Conclusion

The main objective of the research was developed by this algorithm. The adaptation system proposed could solve the problem of redundant leg mobility and terrain irregularities of the robot. This article has presented two algorithms for free locomotion which gives the solutions to these problems.

The adaptation systems proposed allows the robot displacements in the irregular terrain and different robot morphology thanks to the adaptability of the membership function and the alpha cut.

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