Journal of Advances in Computer Research
Quarterly ISSN: 2008-6148
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 3, No. 3, August 2012), Pages: 65-74
www.jacr.iausari.ac.ir

A New Method of Mobile Robot Navigation: Shortest Null Space

Mehdi Ghanavati

Department of Mechanical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

m.ghanavati@mahshahriau.ac.ir

Received: 2012/04/31; Accepted: 2012/07/17

Abstract

In this paper, a new method was proposed for the navigation of a mobile robot in an unknown dynamic environment. The robot could detect only a limited radius of its surrounding with its sensors and it went on the shortest null space (SNS) toward the goal. In the case of no obstacle, SNS was a direct path from the robot to goal; however, in the presence of obstacles, SNS was a space around the robot where fewer or no obstacles existed. In every time step, the robot went to null space. The simulation of robot navigation by SNS method showed that SNS can be a simple and very robust method.

Keywords: *Shortest null space, Navigation, Mobile robot, Unknown environment*

1. Introduction

Robot navigation is the movement of a robot in its environment and reaching the goal without obstacle collision. Many techniques have dealt with this navigation problem. In general, the research in this field can be classified into two major areas: global navigation [1,2] and local navigation [3,4]. In the global one, the environment surrounding the robot and the position of obstacles are known in advance and the robot is required to navigate to its goal by avoiding the obstacles. The complete robot path in such applications can be calculated from the prior knowledge of the coordinates of the starting point, the goal point and the obstacles.

On the other hand, the local motion planning methods dynamically guide the robot according to the locally sensed obstacles, which requires less prior knowledge about the environment. Therefore, local navigation planning methods are more suitable and practical for mobile robots [5]. Some methods include evolutionary programming-based fuzzy logic [6], road map method and Q-learning [7], sensor-based fuzzy navigation of an autonomous mobile robot in an indoor environment [8], vector field histogram (VFH) [9], indoor mobile robot navigation using monocular vision [10] and the potential field method [11] and its variants [12,13]. The basic idea behind this method is to fill the robot environment with a potential field in which the robot is attracted to the target position and is repulsive away from obstacles. In any position, the robot calculates the position with the global minimum repulsive force and moves toward this position; this method is repeated as much as required until reaching its target [14]. Most of pervious methods have some problems such as local minima, complexity and slowness or they are only used in a certain environment like a static environment, outdoor environment, fixed goal, known environment or only for soccer robot with the certain size obstacles [15]. Some methods need learning time, like reinforcement algorithm [16]. In this paper, the shortest null space method was introduced for the navigation of a mobile robot in any environment. This method was local and reactive navigation and did not have any problems of pervious above-mentioned methods.

2. Motivation

The purpose of this paper was to present a fast, simple and robust method for robot navigation which can achieve to the target and avoid obstacles in all environments. Humans always tend to go to the null space when faced with obstacles. Which sides are blank? There is always a null side. If the robot goes blank, it always reaches the goal unless there is no physical way . The shortest null space navigation is a unique approach that requires no memory and no learning.

3. Related Works

Establishing successful navigation policies for continuous and complex environments is an important challenge, particularly when the environment can be only partially observed by the robot. This can be accomplished in a variety of ways, including using physical models of the robot and the environment in which it operates to determine the limits of functionality and interaction [18].

Recently, there have been many interesting studies in the literature for the navigation of mobile robots. The earliest algorithms for robot navigation were developed in a completely known environment, filled with stationary obstacles whose positions were also known. In these algorithms, the widely utilized methods are the artificial potential field (APF) approach [4], the distance function (DF) approach [19], vector field histogram (VFH) [20] techniques and rule based (RB) approach [21].

The APF approach [4] involves modeling the robot as a particle in space, acted on by some combinations of attractive and repulsive fields. In this technique, obstacles and the goal are modeled as charged surfaces and the net potential generates a force on the robot. These forces push the robot away from the obstacles while pulling it towards the goal. The robot moves in the direction with the greatest negative gradient in the potential. Despite its simplicity, this method can be effectively used in many simple environments.

In general, planning techniques utilize such models as well and have been also proven successful for navigation in unknown environments and control of spacecraft [22]. Model-free learning algorithms such as reinforcement learning can be also used for navigation applications [23]. Various types of reinforcement learning have been also successfully applied to free gait development [24].

4. Kinematics and Modeling of Chamro Robot

The robot that was used in the paper was a differential drive wheeled mobile robot, called Chamro. It could do five actions: go ahead, turn right, turn left, circle left and circle right. The robot and its eight sensors are shown in Figs. 1 and 2. These infra-red sensors were used for local cognition around the robot and the range of sensors was 10 cm.

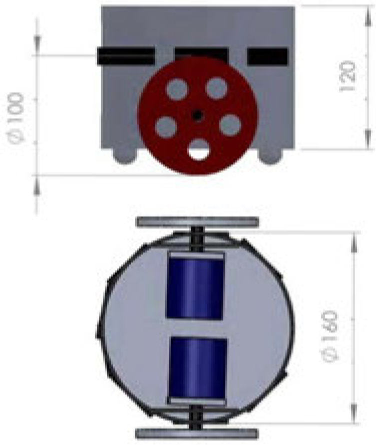

Figure1. Chamro robot with its size in mm

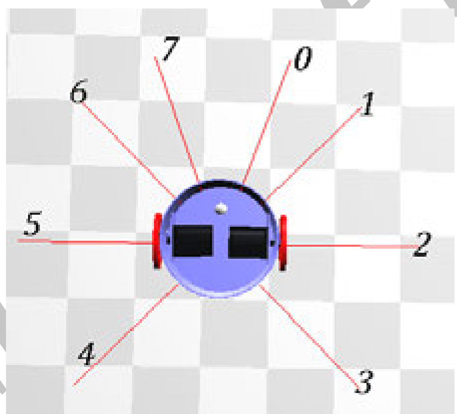

Figure2. Chamro robot with eight sensors

The kinematics for the differential drive mobile robot under no slipping, pure rolling and no sliding constraints is given in Equations1, 2 and 3.

$$\begin{bmatrix} \dot{x} \\ \dot{z} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{1}$$

$$v = \frac{r}{2}(\omega_r + \omega_l) \tag{2}$$

$$\dot{\theta} = \frac{r}{L}(\omega_r - \omega_l) \tag{3}$$

where v is linear velocity of the robot in front direction, $\dot{x}$ and $\dot{z}$ are global velocity of the robot in x and z directions of a world coordinates. $\dot{\theta}$ is an angular velocity of robot around the y axis. ω_r is the angular velocity of right wheel and ω_l is the angular velocity of left wheel. θ is the orientation angle of the robot with respect to the north direction (z axis). L is length of axle and r is the radius of wheels. The variables are shown in Figure 3.

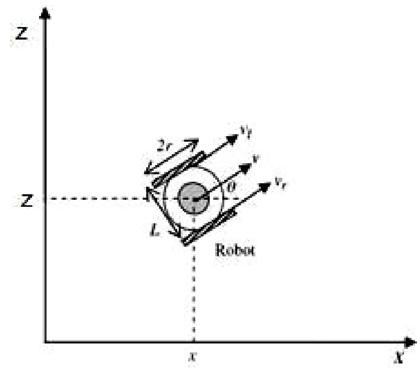

Figure3. Robot variables in the global frame

5. Navigation Using SNS Method

SNS navigation is divided into two parts; without obstacles and with obstacles. In the first part, the robot goes on the shortest trajectory from the beginning to the target.

5.1 Without Obstacles

The robot uses its location and goal location to go to the target. The target can be a certain point. To reach the goal, the robot needs some angles, which are given in Figure 4.

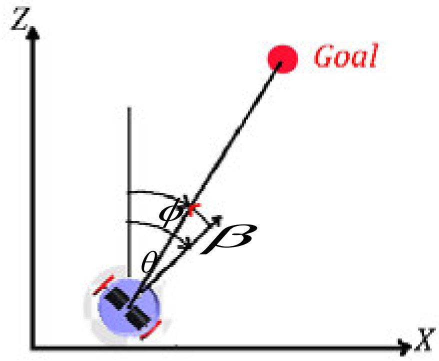

Figure4. Orientation angle of the robot and error angle

ϕ is the angle between the robot-goal line and north direction (zaxis). β is also the difference between these two angles (desired angle and current angle) and is obtained by Equation 4.

$$\beta = \theta - \phi \qquad (4)$$

When no obstacle exists, the shortest null space is a direct line from the robot to goal. So, the robot goes to the goal with three rules according to Equation 5.

$$\begin{cases} \beta > 0.05\,rad \rightarrow Circle\ \ left \\ -0.05\,rad < \beta < 0.05\,rad \rightarrow go\ ahead \\ \beta < -0.05\,rad \rightarrow Circle\ \ right \end{cases} \quad (5)$$

When the robot turns left, the right wheel is derived faster than the left one, like Figure 5. And, circle right is inverse. Webots[1], robot simulation software, was used for the simulation of robot and environment.

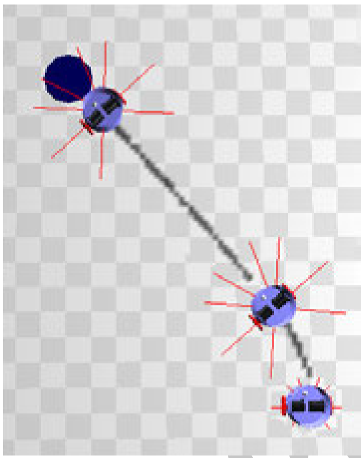

Figure5. Turning left and then going ahead toward the goal

5.2 In the Presence of Obstacles

When obstacles exist, SNS is a variable with respect to the size of obstacles. Three sides around the robot are defined which include front (ir0, ir1, ir6 and ir7 sensors), left (ir5, ir6, ir7) and right (ir0, ir1, ir2). When the robot senses an obstacle, it compares the null space around itself. Three variables are defined; H is the number of front sensors that sense the obstacles, R is the number of right sensors that sense the obstacles and L is the number of left sensors that sense the obstacles. Table 1 shows the null space sides and sets.

Table1. Sets and null space sides

Number of sensors	Null space side	Set	Range of set
0 ,1,6,7	Front (head)	H	{0..4}
5,6,7	Left	L	{0..3}
0,1,2	Right	R	{0..3}
3 and 4	Back	B	{0..2}

For example, if the sensor number 0 and sensor number 1 sense an obstacle, then L=0, H=2 and R=2. Therefore, the null space is left; so, the robot turns left. The shortest null space method has three rules:

1. www.cyberbotics.com

If (H=0) then go to goal by Eqe.5
Else{
If (L > =R) then Turn right
Else if (R > L) then Turn left
}

Turning right means left wheel velocity is positive and right wheel one is the same as the left but negative.

In Figure 6, the result of SNS rules is given, where L and R are equal to one and H=2. So, the robot turns right.

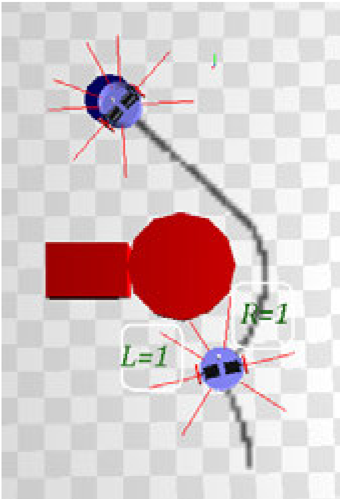

Figure6. Chamro turns around the obstacle

5.2.1 Moving Obstacles

When the robot is faced with a moving obstacle, SNS rules are established but five actions are fast with respect to the obstacle speed, as shown in Figure 7.

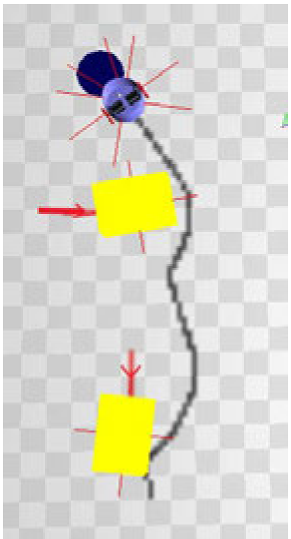

Figure7. Avoidance of two moving obstacles

6. Discussion and Comparison

Other navigation methods have a local minima or a foible, in which the robot fails. The potential field method suffers feom local minima in some situations which are given in Figure 8-a [17]; however, SNS does not have any minima or foible (Figure 8-b).

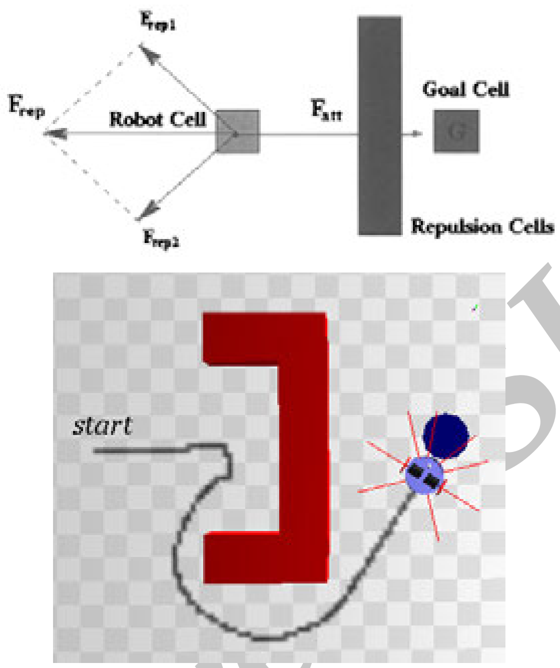

Figure8. a, Local minima in PF. b, SNS method passes a U obstacle

Using SNS method, a robot always achieves the goal unless there is a no physical way. Limit cycle navigation method cannot go to the back of a ball when the ball is behind the robot [15]; however, SNS navigation method can do it and SNS also does not need size or position of obstacles. Three virtual around obstacles can be inserted [15] around the ball to go to the back of the ball (Figure 9).

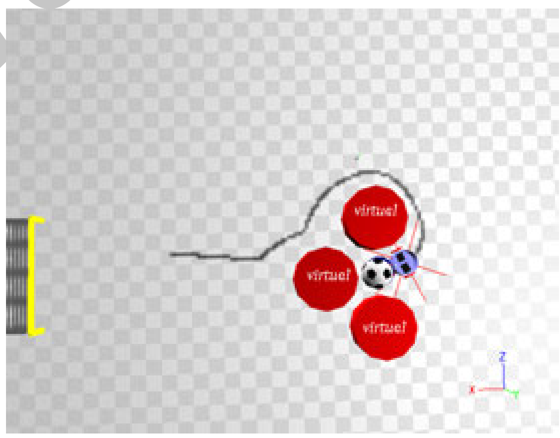

Figure9. Chamro goes to the back of the ball using three virtual obstacles technique

SNS navigation is faster and smoother than reinforcement learning method [14] and many optimization navigation methods. Figure 10 shows this comparison: the robot runs by 0.2 m/s velocity. The distance between the goal and robot is 4.85 m. SNS method takes 20 sec time and reinforcement method takes 25 sec time.

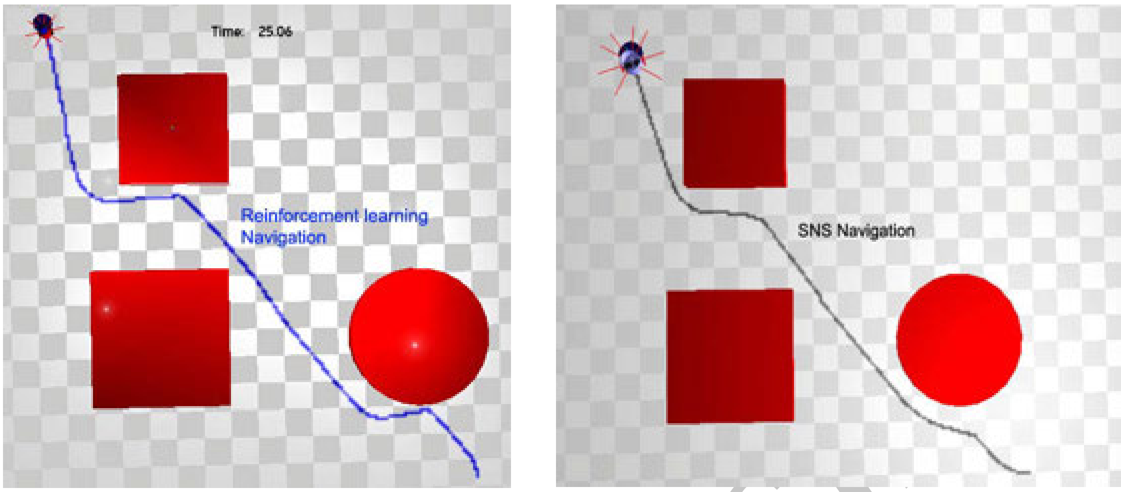

Figure10. The comparison between reinforcement learning method and SNS navigation method

SNS can follow a moving goal such as a ball or other robots in the presence of any obstacles (Figure 11). It can also follow sequential goals along a path like the sinuous path (Figure 11). For this work, many points of a path were given; then, the robot went to these points sequentially using Equation 5.

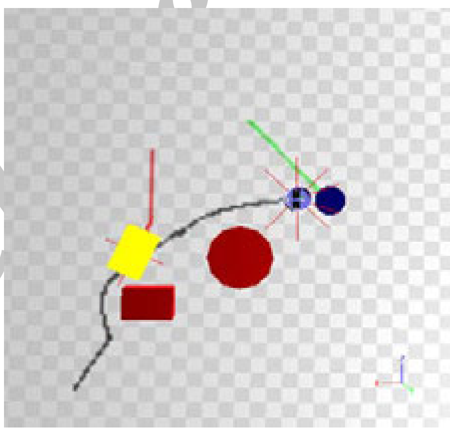

Figure11. Following the moving goal (green line)

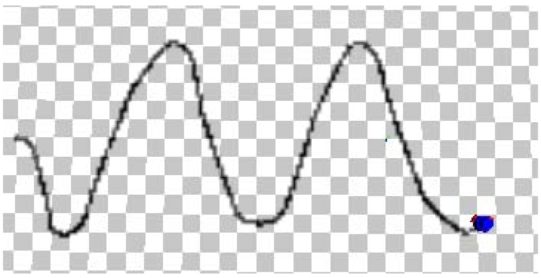

Figure12. Following sequential goals on the sinuous path

For indoor navigation, SNS method only needs some middle goals to go out of the rooms. After that, the robot can go to every goal. The simulation of SNS with the middle goal 1 indoor is shown in Figure 13.

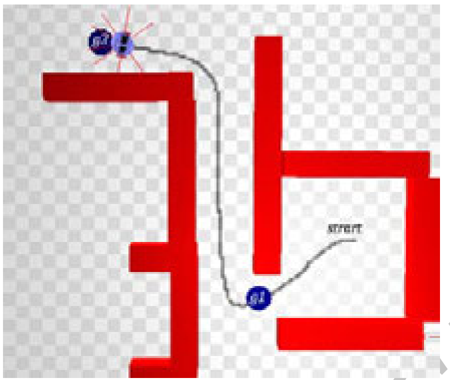

Figure13. Indoor navigation by SNS method

Other methods cannot do different things at the same time, like an indoor navigation, outdoor navigation, sequence move, navigation with moving goal, dynamic obstacles, unstructured environment and unknown environment. But, SNS can do them. In additional, the shortest null space navigation is a unique approach that requires no memory and no learning.

7. Conclusion

The shortest null space is a very simple and robust method for navigation. It is derived from human actions in the face of obstacles. Humans always go to null spaces. SNS is a local navigation without learning and without requiring time for decision. SNS can do more obstacle avoidance with any size and anywhere, either fixed or moved. It can also follow moving goals fast. SNS with the middle goals in the path can do navigation in the indoor environment. It is useful for a soccer robot yet without global vision. SNS has only one general rule : going on the shortest null space toward the goal.

Biographical Notes

Mehdi Ghanavati received his MSc degree in Mechanical Engineering from Islamic Azad University, Ahvaz Branch, in 2009. He is currently a teacher in the Department of Mechanical Engineering, Islamic Azad University of Mahshahr, Mahshahr, Iran. His current research interests include mobile robots and humanoid robots.

8. References

[1] Warren C. Global path planning using artificial potential fields. In: Proceedings of the IEEE international conference on robotics and automation, Scottsdale, AZ; 1989. p. 316–21.

[2] Kambhampati S, Davis L. Multiresolution path planning for mobile robots. IEEE J Robotics Autom 1986;2:135–45.

[3] Khatib O. Real-time obstacle avoidance for manipulators and mobile robots. In: Proceedings of the IEEE international conference on robotics and automation, St. Louis, MO; 1985. p. 500–5.

[4] Borenstein J, Koren Y. Real-time obstacle avoidance for fast mobile robots. IEEE Trans Syst Man Cybern 1989;19:1179–87.

[5] R. Abiyev, D. Ibrahim,Navigation of mobile robots in the presence of obstacles, Advances in Engineering Software 41 (2010) 1179–1186
[6] M.-S. Lee, M.-J. Jung, J.-H. Kim, Evolutionary Programming-based Fuzzy Logic Path Planner and Follower for Mobile Robots, in: Congress on Evolutionary Computation, vol. 1, San Diego, CA, July 2000, pp. 139–144.
[7] Maki K. Habib, Shin'ichi Yuta, Map representation of a large in-door environment with path planning and navigation abilities for an autonomous mobile robot with its implementation on a real robot 1993, Automation in Construction, Volume 2, Issue 2, Pages 155-179
[8] Tsourveloudis N, Valvanis K, Herbert T. Autonomous vehicle navigation utilizing electrostatic potential fields and fuzzy logic. IEEE Transactions on Robotics and Automation 2001;17.
[9] Borenstein J, Koren Y. The vector field histogram – fmt obstacle avoidance for mobile robots. IREE J Robotam Autom 1901.
[10] Mao-Hai Li, Bing-Rong Hong, Ze-Su Cai, Song-Hao Piao, Qing-Cheng Huang, Novel indoor mobile robot navigation using monocular vision, Engineering Applications of Artificial Intelligence 2008, Volume 21,pages 485–497
[11] Khatib O. Real-time obstacle avoidance for manipulators and mobile robots. The International Journal of Robotics Research 1986;5:90–8.
[12] Ge S, Cui Y. New potential functions for mobile robot path planning. IEEE Transactions on Robotics and Automation 2000;16:615–20.
[13] Tsourveloudis N, Valvanis K, Herbert T. Autonomous vehicle navigation utilizing electrostatic potential fields and fuzzy logic. IEEE Transactions on Robotics and Automation 2001;17.
[14] Abdel kareem. m & Al-Rousan. m, Reinforcement based mobile robot navigation in dynamic environment, Robotics and Computer-Integrated Manufacturing 2011, volume 27, pages 135-149
[15] Dong-Han Kim, Jong-Hwan Kim, A real-time limit-cycle navigation method for fast mobile robots and its application to robot soccer, Robotics and Autonomous Systems, Vol 42, Issue 1, January 2003, Pages 17-30
[16] Neda Daei, Hossein M. Shirazi, Reza Askari, Mehdi Ghanavati, "Service Robot Navigation Based on Q-Learning and Fuzzy Logic", IJREA: International Journal of Robots, Education and Art, Vol. 1, No. 2, pp. 1 ~ 9, 2011
[17] Arambula cosfo.f and Padilla castai.m, autonomous robot navigation using adaptive potential fields, Mathematical and Computer Modelling, Vol 40, 2004, pp 1141-1156
[18] T. Balch, R.C. Arkin, Communication in reactive multiagent robotic systems, Autonomous Robots 1 (1) (1994) 27–52.
[19] Gilbert EG, Johnson DW. Distance functions and their application to robot path planning in the presence of obstacles. IEEE J Robotics Autom 1985;1:21–30.
[20] Borenstein J, Koren Y. The vector field histogram – fmt obstacle avoidance for mobile robots. IREE J Robotam Autom 1901.
[21] Li W. Perception–action behavior control of a mobile robot in uncertain environments using fuzzy logic. In: Poceedings of IROS-94; 1994
[22] S. Koenig, C. Tovey, Y. Smirnov, Performance bounds for planning in unknown terrain, Artificial Intelligence 147 (1–2) (2003) 253–279.
[23] R.S. Sutton, A.G. Barto, Reinforcement Learning: An Introduction, MIT Press, Cambridge, MA, 1998.
[24] M.S. Erden, K. Leblebicioğlu, Free gait generation with reinforcement learningnext term for a six-legged robot, Robotics and Autonomous Systems 56 (2008) 199–212.