The Study on Optimal Gait for Five-Legged Robot with Reinforcement Learning

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Abstract. The research of legged robot was rapidly developed. It can be seen from recent ideas about new systems of robot movement that take ideas from nature, called biology inspired. This type of robot begins replacing wheeled robot with various functions and interesting maneuvers ability. However, designers should decide how many legs are required to realize the ideas. One of the ideas that are rarely developed is odd number of legs. This research focused on five legs robot that inspired from starfish. To realize the intelligent system in robot that does not depend on the model, this research used reinforcement learning algorithm to find the optimal gait when robot is walking. In order to achieve this goal, trial and error have been used to provide learning through an interaction between robot and environment based on a policy of reward and punishment. The algorithm is successfully implemented to get the optimal gait on a five-legged robot.

Keywords: Five-legged robot, gait optimizing, reinforcement learning.

1 Introduction

At the first stage in design of a walking machine, designers should decide how many legs are required to realize the ideas. Presently, biped, quadruped and hexapod machines occupy large volume in researches of practical walking robot. It is debatable which number of the legs is better, four or six. We should select the number of legs carefully by considering their locomotive environments, because each walking machine has peculiar merits. In case of heavy walking environments, hexapod walking may be more suitable than quadruped walking. If one of the six legs is broken down, continuation of the static walking may be ensured by the left five legs, while some parts of walking functions are reduced. In case of quadruped walking robot, it may not be possible to continue their static walking.

According to bionics, six legs/hexapods robot may be a better choice. On the other hand, almost all insects have six legs [1]. It easy to keep balanced with a redundant locomotion system, which increases reliability and workable even if one, two or three

M. Xie et al. (Eds.): ICIRA 2009, LNAI 5928, pp. 1170–1175, 2009.

legs broken. Hexapod makes it possible for the robot to use one, two or three legs to work as hand and perform complex operations.

2 Related Work

As the reasons why the gait study of walking with odd number of legs is very few as compared with the gait study for even number of leg, the following matters are considered. Although we can easily find probable gait for the walking with even number of legs by observation of insects etc., this method is not available for the case of the walking with odd number of legs. In the fact, the wave gait which is for the walking with even number of legs is originated from the observation of insects' walking, and the above mentioned analytical proof is performed with an assumption that the wave gait is optimally stable. It is very difficult to come to the same conclusion by use of analytical method without the assumption of the wave gait [2].

Studies of the gait of the partially broken hexapod machine have been discussed from biological observations. Inagaki and Kobayashi [3] described in hexapod walking robot, it is considered that even if one of six legs is disabled, the remaining five legs may maintain static walking. However, to maintain the static stability at maximum, gait study for five-legged walking is necessary. They developed a method of gait study for five-legged walking, which is considered a case that hexapod walking robot damaged in one of six legs. The allowed leg arrangement, which means the arrangement of the center positions of stroke motion, to maintain the gait stability margin is only limited to the regular pentagonal shape. Thus, in the case that a hexapod walking robot which has general leg arrangement such as a rectangle type is damaged, the leg arrangement must be changed to the pentagonal shape. Thus, these gaits are enough useful as a gait for five-legged walking. Nowadays, the studies of five legs robot not just inspired from hexapod walking with disabled leg but inspired from nature that got the idea from starfish. Makoto et al. [4] focus Brittle Star realizes a flexible myriapod robot. Brittle Star is a kind of the Echinoderm has five long legs. They developed the five legs robot, and inquire forward motion it.

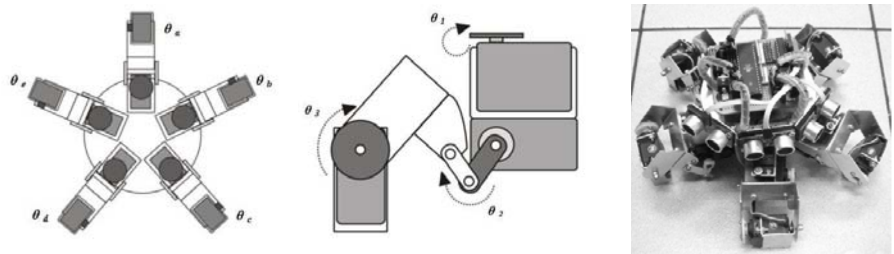
On the other hand, synchronized motion is very important for the multiple legged machines. This paper proposes a synchronized motion method that utilizes the notion of autonomous distributed systems. For the method, we have reviewed how quadrupeds [5], [6], [7], [8] and hexapods [9], [10], [11], [12], [13] on locomotion aspects and compared those methods. Most of the methods use degree of freedom (DOF) settings as the main parameter of walking robot. Finally, we show the total motion control can generate the gait automatically and change them smoothly by using reinforcement-learning algorithm.

3 System Design

Most of the systems use the natural movement of the whole number of feet (two, four, six and eight). Five-legged in the design of nature can be found on the starfish. The design is inspiring authors to develop this type of robots. The learning of five-legged walking is realized with the actual robot. This section introduces the system design of robot and application of reinforcement learning for this purpose.

3.1 Mechanical and System Design

Mechanical design of robot developed with five-legged actuator. It has five legs, and on every corner, there is three degree of freedom as a reference for the movement of robots. The kinematics system design and prototype of robot are shown in Figure 1.



(a) Kinematics design (b) Design of one-leg (c) Prototype of robot

Fig. 1. Design and prototype of five-legged robot

The system is divided into several sections: actuator and sensor selection, mechanical and hardware building, and next reinforcement learning algorithm implementation in robot. The type of actuator that selected is standard servo-motor (180 degree rotation) with a high enough torque (4.1kg.cm/56.93oz.in). Limit switch is used to detect position of the robot. Limit switch installed in each leg. When the limit switches are touching objects, it will send a data series (USART) to microcontroller to drive servo motor.

3.2 Learning Algorithm

The reinforcement learning makes the robot adapt to more stable gaits in normal conditions of no external effect of instability. As a result, the stability of walking with a commanded speed is continuously increased till a pattern having good stability margin with each state is achieved. When the speed command is changed, the robot performs a smooth passage with probably slowing down to the speed of 1 unit per step, and then adapting to the new speed in a few steps. This smooth passage between commanded speeds should be noted as a peculiar feature of the algorithm.

Among the possible gaits with a given speed there are some applications with more static stability, while there are some applications that hardly satisfy the stability condition. Improvement of stability can be achieved by learning with the best state transitions are memorized and utilized. In this application the robot is not aware of the cause, but experiences falls although it generates statically stable gaits. The falls result in negative reinforcement and the robot learns to avoid them by memorizing and making use of the stable states.

In this design, reinforcement learning discussed to determine the optimal movement in robot walking. Reinforcement learning algorithms that are generally used apply several parameters that change according to the learning process in robot. In each of parameters, there are functions that are defined first. Angle on hinge base and delay are parameters that have been chosen. These parameters changed the established value. The program that created generally divided into walking description includes the determination of the motions that can be done by robot. It includes testing of learning function that gives the optimal results in walking in the field with several conditions.

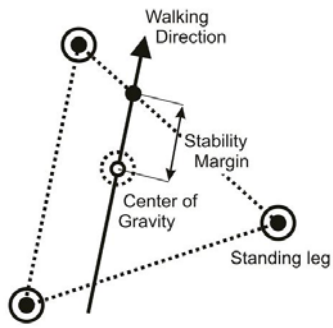


Fig. 2. Stability margin

Angle joint on hinge base of the legs, as shown in Figure 3, is referred to the point that can be reached by leg movement of joints that are closest to the body of robot (center of body). Because there are five legs, between the legs with one leg to the other leg is 72° away. So that each leg can move 72° (clockwise) and -72° (counter clockwise). But in reality, robot can only reach -50° to 50° because of mechanical robot legs require some space. Velocity of robot is resulted by time delay every movement joint on the robot legs. This parameter is given on the value of the function of delay in the microcontroller program. Before calling this function, interrupt will be turned off, and time delay will be longer than expected. Assessment is done by giving a "reward" when the movement of robot that have been produced in accordance with the environment condition, or by giving a "punishment" when the movement that produced robot are not appropriate. If "punishment" is received, means punishment point is added and the value of the parameters changed. If "reward" is received, means reward point is added and the value of parameters stored in memory. Every step described by the recursive functions.

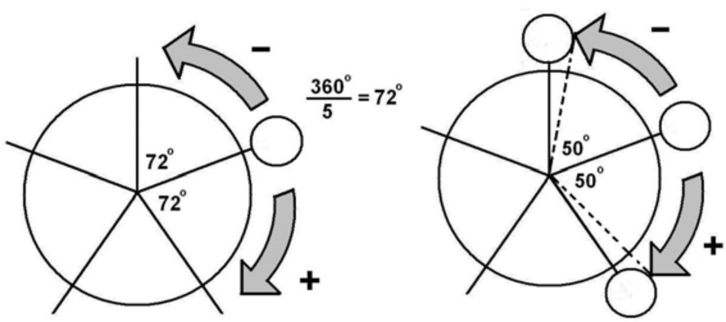


Fig. 3. Angle joints which formed the base of leg and the reduction

4 Result

Learning algorithm has been tested in the actual conditions. The robot is tested on several different levels of slope (0°, 10°). Error slope has been chosen as parameter that can be compared in measuring level of learning success. This parameter becomes the benchmark to get the most effective and efficient gait of robot. From here, we can conclude that the program algorithms can be created to run the system properly in accordance to criteria that are expected. Testing results in several different levels of slope that compared in error slope parameter are shown in Figure 4.

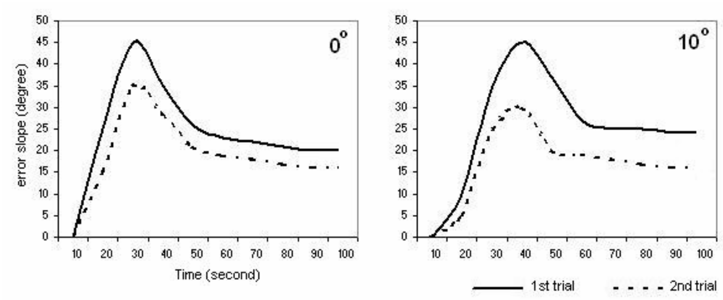


Fig. 4. Walking on several different levels of slope (0°, 10°)

5 Conclusion

This research focuses on five legs robot inspired by starfish. To realize the intelligent system in robot does not depend on the model, reinforcement learning algorithm used to find the optimized gait in walking robot. To achieve this goal, trial and error is used to provide learning through an interaction between robot and environment based on a policy of reward and punishment.

The speed on the walking robot depends on time delay, the greater delay reduces speed. Furthermore, error slope depends on the speed of movements. More rapid movement of servo motor causes greater error slope. Smaller angle that formed made greater error. In order to obtain the maximum results required a large torque in servo motor, so that the robot can hold the movement. Synchronization of movement between the legs on the robot can affect by considering time delay between gaps of movements. Locomotion of five-legged robot is shown in Figure 5.

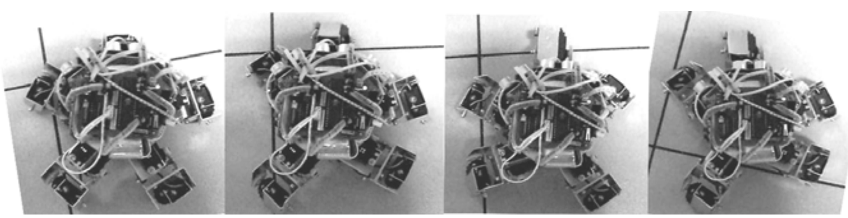


Fig. 5. Experiment on flat and sloping road and five-legged robot locomotion

Acknowledgments. The authors would like to thank Electronic Engineering Polytechnic Institute of Surabaya (EEPIS) supported by Japan International Cooperation Agency (JICA) under PREDICT Project for developing the five-leg robot, Universiti Teknikal Malaysia Melaka (UTeM) and Universiti Kebangsaan Malaysia (UKM) for financial support and providing facilities.

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