Quadruped Robot Guided by Enhanced Vision System and Supervision Modules

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Abstract. Legged robots taking part in real multi-agent activities represent a very innovative challenge. This domain of research requires developments in three main areas. First the robot must be able to move efficiently in every direction in its environment. The faster the motion, the better it is. Special care must be taken when designing walking pattern transitions. Then, without any exteroceptive sensor to get information about its surroundings, the robot is blind. Fortunately, the quadruped prototype on which all experiments are carried out is equipped with a enhanced vision system and vision is the best means of getting a representation of the world that can be found in Nature. Finally the machine should be brought a minimum of intelligence since it has to manage vision information and its walking gaits by itself. When involved in cooperation, confrontation or both like in the soccer play, a high level supervision task is welcome. This paper presents detailed developments of these three points and describes how they are implemented on the real robot.

1 Introduction

The LRP legged machines team has been given the opportunity to participate in the Legged robots RoboCup competition which was held in July 1998 in Paris. Sony Corporation and specifically the D21 Laboratory in Tokyo lent very kindly three pairs of "pet robots" to three teams in the world. These prototypes represent a high level development platform on which to put into practice optimized algorithms of locomotion and vision. Behavior strategies can also be included after testing on simulation.

Having in mind that three robots must cooperate to score a goal in the opponent player goal, two kinds of strategies are considered. The first one has to answer the following question : how to incorporate the three functions mentioned above : locomotion, vision and supervision, and how are they going to interact with each other in an efficient manner ? This strategy of implementation is very important since all tasks are to execute on-board in real time. The second strategy is the decision-level one to adopt on the soccer field to win the game.

The first section of this paper is dedicated to the walking patterns used to make the robot move quickly in every direction. In the second section the different steps of the

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vision recognition and localization procedures are explained. The third section is devoted to the strategy employed for the robots to play football.

2 Legged Locomotion

Legged locomotion has been implemented using the fundamental principles developed by McGhee in [1],[2]. Forward, bacward, turning and rotation motions have been derived from the crawl model. Forward and backward gaits have been improved thanks to a special sideways motion [3]. The two next sections deal with turning and rotation gaits.

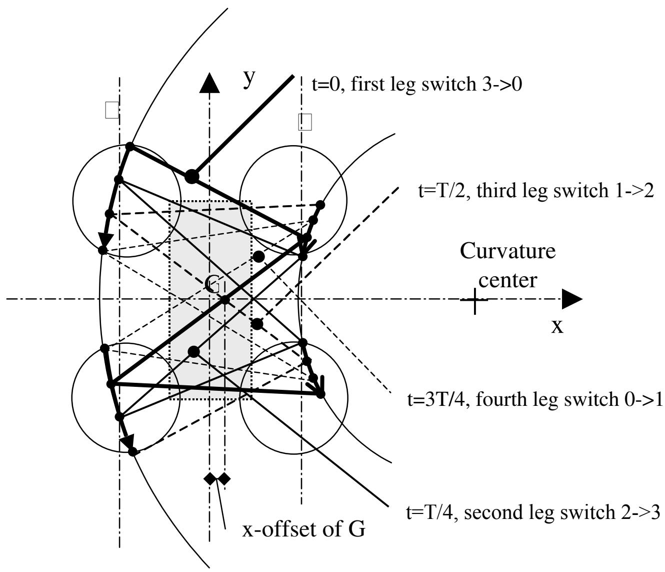

Fig. 1. Successive support polygons for right turning gait at fractions of cycle time of 0,1/4,1/2 and 3/4

2.1 Turning Gaits

This section focuses on turning gaits. The strategy adopted here is to define turning motions whose curvature center is located on the transverse axis of the robot. This will enable the machine to turn right or left with a varying turning circle. The idea consists in adapting the forward sideways crawl. Since it has been decided to exclude prediction features in the definition of the gait, such as predicted duty times or predicted footholds for instance, it seems difficult to master transitions at any moment of time. To avoid this problem turning gaits are designed in such a manner that they share a common set of footholds with the forward walking pattern at a particular instant of cycle time. Fig. 1 shows the common set of footholds for right turns on lines □ and □'.

The configuration for right turning refers to the foothold positions of the legs in the forward motion at instant of T/4, and for left turning, it corresponds to positions of legs at 3T/4. The exact distance traveled by the leg in the traction phase with respect to the body reference frame is computed to be approximately equal to the one defined in the forward motion, this is to guarantee continuity of speed. The sequence of legs is the same as in the crawl leg state diagram [1].

However the COG must be shifted so as to be on the diagonal supporting line when transitions 3->0 and 1->2 occur, see fig. 1. Moreover the sharper the turning circle, the larger the amplitude of the sideways motion is. When the turning circle is shorter, the incline of the diagonal supporting line increases, and amplitude must be increased. Besides, lateral stability limits the magnitude of lateral oscillations. Therefore, there is a threshold turning circle under which it is not possible to use the same technique any more. This threshold is approximately equal to the length of the machine, that is about 15 cm. Finally it must be noticed that right and left turns converge towards forward crawl gait when the turning circle tends towards infinity.

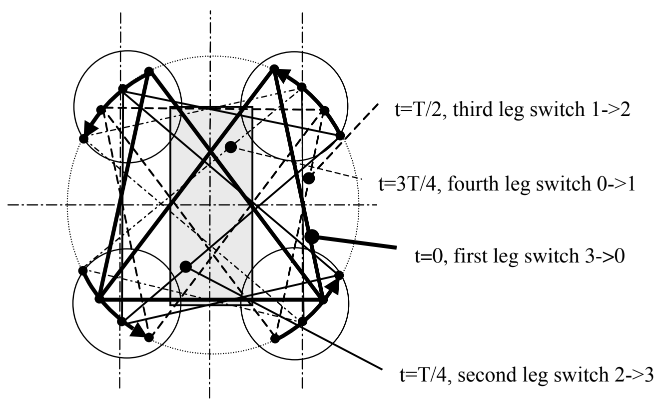

Fig. 2. Successive support polygons for right rotation at fractions of cycle time of 0,1/4,1/2 and 3/4

2.2 Rotations

Since the goal is to design efficient motion of the robot in every direction, it is interesting to define a rotation motion around the COG. The first step is to find a common set of leg footholds for the transitions. The configuration is given by the intersection between the trajectories in straight line motion and the circle spotted in fig. 2.

Transitions can occur at T/4 or 3T/4, depending on the initial and final motions.

One important point in rotation motion is that phase differences between legs are changed. It is not a symmetric gait any more, that is, opposite legs are no more half a cycle period out of phase. The successive support polygons are plotted in fig. 2.

Obviously there is no need for sideways displacement of the COG. Rotations in clockwise and counterclockwise directions are straightforward, transitions between them can trigger at any time without problem.

3 Vision System Module

The goal of the vision system is to detect, to identify and to spot the different elements constituting the scene during the play. "Detecting" means extracting all connected components belonging to the scene elements from the color images . "Identifying" means finding the sole or the several connected components constituting an object of the scene and giving it a symbolic label such as ball, beacon, own or opponent goal, partner or opponent player, edge of the soccer field. "Spotting" beacons or goals means determining the view angle in azimuth with respect to the head direction and a "rough" measurement of the distance between head and target.

3.1 The Detection Step

The detection step is composed of the five following algorithms :

1. Color Detection, performed by the Sony specific hardware using threshold values as input controlled parameters and providing output in the form of 8 bit-planes, each corresponding to a color template.
2. Opening performed simultaneously on each of 8 bit-planes, using an isotropic 3 by 3 centered neighborhood. It cleans the "8- binary" image of pixels resulting of color detection from noise.
3. Connected Component Extraction [4] which requires a single scan of the image, detects equivalent labels, and computes the connected component attributes : gravity center, surface, including box.
4. Filtering on the surface attribute of the connected components to remove too small components due to bad lighting conditions.
5. Merging of connected components, to deal with bad lighting conditions responsible for the decomposition of a scene object into several connected components. To be merged, two connected components must have their including box close to each others. An “image object” resulting from the merging of several connected components is not a connected component. But its parameters such as surface, gravity center, including box are computed directly from parameters of merged connected components.

Steps 1, 2 and 3 are low level image processing, applied to image data. Steps 4 and 5 are intermediate level image processing, applied to feature attributes : they are fast to perform.

3.2 The Identification Step

The ball is a small scene object which may be partly or wholly occluded, and generally it does not produce more than a single image object. So the ball identified in the image is the image object corresponding to the orange color template, whose surface is maximum.

Beacons are also small scene objects, but they are localized in such a way that they cannot be occluded. They are composed of two colors : one necessary pink, the other

yellow or blue or green. Taken into account the geometry of the camera and the soccer field, two beacons can be viewed at most. An identified beacon is composed of two image objects, the first is necessary pink, the second is yellow, blue or green, and the two image objects are located one above the other.
Goals are yellow or blue, but they have the same colors as the beacons. The goals are seldom viewed entirely. Either the robot is far from the goal, and the goal is certainly occluded by one or more players, or the robot is close, and the goal comes out of its field of view. So, the identified goals are the image objects (blue or yellow) which are not identified as a beacon.
Players are either dark blue or red. But, depending on their direction, they appear constituted by one or two image objects.
The edges of the soccer field are white. It is the last available template color!

3.3 The Localization Step

The angle in azimuth with respect to the head direction is computed from the x component of the gravity center of the identified object, knowing the image resolution on the x axis and the horizontal field of view of the video camera (52°), assuming the pin hole model of camera.

A "rough" measurement of the distance between the head and a scene objet is given by a look up table based on the surface attribute for the ball and the beacons, the height of the including box for the goals. But it seems impossible to give a reliable rough measurement of the distance from another player, because all feature attributes change for a great part when the player rotates on itself at the same distance! But an "alert" is generated if the surface of the image object of a player grows up beyond a threshold value, to stop the robot and consequently to avoid collisions.
A "rough" measurement of the distance from the robot and the edge of the soccer field is geometrically computed.

In conclusion, the cadence of image processing, measured by two different benchmarks is about 14 or 15 frames per second, while the robot is walking. In these conditions, the head can rotate smoothly to track the ball.

4 Behavior and Strategy of Quadruped Robots

Having two teams of three robots allowed to considerate the whole game as a Multi-Agents System. The main difficulty we encountered was the communication between agents (i.e. robots). As a matter of fact, viewing at each over, using an embedded vision system, was the only way for robots to communicate and locate their own position on the field.

The idea was to allow the quadruped to be able to quickly swap between planning and reactivity; that is to say that pet should be able to generate a trajectory, for instance, to kick the ball, or protect is own goal, and give up all is plans at the next decision cycle if the situation has changed.

With regard to strategy, we used a "Buckett Brigade" type algorithm : Each agent has a rule system, and a weight is associated to each rule. Applying a rule means, for an agent, to choose a role, that is to say a specific behavior, for instance a role as a Kicker or a Defender. During the game, weights are dynamically modified : the weight of a rule is increased if applying this rule allow the pet to kick the ball or even to score a goal, otherwise, the weight is decreased.

We build a simulator for Windows 95 which uses the real pet's odometry parameters. Playing several games in this simulator allows the quadrupeds to learn how to select the right role for a given game situation by adjusting the rules' weights.

Further work can be explored in the two following domains:

 Pattern recognition and Learning : to learn the pet how to build a model of his environment is not a trivial problem. The robot must be reactive enough to avoid unexpected problems such as a chair or a table which has been recently moved in the room. At the same time, it must be able to reach is goal, in an efficient way, that means to plan his trajectories and actions.

 Cooperation between pets, to achieve a common task, for instance cleaning a room by pushing objects too heavy for one and only robot. This point is directly linked to soccer strategy. That domain is strongly dependant of vision and walk : to cooperate, robots need to improve their abilities to communicate and move.

5 Conclusion

This paper has described the implementation of turning and rotation gaits derived from the crawl gait. All these gaits were designed under specifications of efficiency and increased velocity. The main axes of the vision system associated with the legged locomotion module have been presented, together with some implementation details of the strategy level. The 1998 Robocup legged robot challenge was the opportunity for our team to face other teams from other foreign countries. Our prototypes showed good abilities in moving on the soccer field tracking the ball.

Efficient implementation of walking is very useful since it makes robots operational to take part in multi-agents cooperation activities. Soccer play appears to be a good testing ground for research in strategy and multi-agent behavior.

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