Nexus 3D 2007 Soccer Simulation Team Description

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Abstract. This paper presents an overview of Nexus 3D Soccer Simulation Team. Our main concentration was on developing a new hybrid methodology for an evolutionary gait generator that uses trigonometric truncated Fourier series formulations with coefficients optimized by a Genetic Algorithm. The Fourier series is used to model joint angle trajectories of a simulated humanoid robot with 25 degrees of freedom. The simulation result shows the robustness of the developed walking behaviors even in extremely high and low speeds providing appropriate frequency. In addition, the proposed solution adapts a hybrid approach, thereby avoiding the long learning curves and unstable and slow gaits associated with evolutionary approaches.

1 Introduction

Nexus Soccer Simulation team is developed by a group of M.S and B.S students of Ferdowsi University of Mashhad, Iran and since establishment in 2002, achieved number of honors in international and local competitions. The current development of 3D Soccer Simulation League leads towards humanoid robots known as *soccerbot* agent, which already can be controlled by a lower level interface. However, controllers for these robots have to be developed in order to provide an easy-to-use interface.

The Nexus 3D 2007 was designed based on automatic evolution of walking behavior in a simulated humanoid with online adjustable speed. A simple PD controller was implemented to control the joint motors, but due to the adaptive nature of evolutionary methods, any other type of controller can be used. Since the movements of the robot are known to be periodic while walking on flat plains, the motion of every joint can be expressed in terms of a trigonometric truncated Fourier series. Coefficients of the Fourier series are determined by using a genetic algorithm. Each individual in the genetic algorithm contains a set of coefficients for every joint's Fourier series, and thus defines a gait. These gaits are then tested in the simulation environment until the robot falls down over the ground or a sufficient amount of time passes by. The fitness is calculated based on the forward movement of the robot and the total time of the test. Once all individuals of the current generation are tested, the next generation is generated by applying GA operators over the best fit individuals.

Using this method, a relatively fast and stable walking gait is evolved within a three-day simulation time on a Pentium IV 2.8GHz machine with 1GB of physical memory.

2 Walking skills

Transferring the weight from one leg to the other, shortening the leg not needed for support, and leg motion along the walking direction are the key ingredients of this gait. Walking forward, to the side, and rotating on the spot are generated in a similar way. As the first step toward a skillful humanoid agent, walking is performed with a traditional control method that follows a set of generated ZMPs[1] along the path. A popular approach used for joint trajectory planning for bipedal locomotion is based on the ZMP stability indicator. In many ZMP-based trajectory planning approaches, motion planning is presupposed and performed in the Cartesian space [1, 2]. Hence, evolving control systems for robot locomotion is becoming a standard approach for the generation of improved or newer control systems for robots [3]. Various learning approaches for bipedal locomotion have been proposed by several researchers. Lin Yang et. al presented the Genetic Algorithm Optimized Fourier Series Formulation (GAOFSF) method for stable gait generation in bipedal locomotion in [4]. They use Truncated Fourier Series (TFS) formulations together with a ZMP stability indicator to generate the feasible gaits for a simple seven-link planar robot. A genetic algorithm is then utilized to search for optimal gaits according to the objective functions considering the specified constraints. Some researches have used genetic algorithm to directly generate joint trajectories for each step [5, 6]. These trajectories are then applied to joints repeatedly while walking. Although this method is successfully utilized for biped robots, the generated gaits can not be changed to achieve desirable real-time motion adjustment.

2.1 Truncated Fourier series

Evolutionary approaches include trying to optimize the parameters of a given type of motion model [7]. Common to these methods is the fact that a certain amount of knowledge of how locomotion is performed is implicitly present in the model. This narrows down the search space thus reducing the time needed for the optimization process. For a deeper look into biped motion properties we recorded and processed HOAP-2 walking gait which is included in the Webots simulation software [8]. The knee and hip trajectories for the HOAP-2 are identical in shape for both legs, but are shifted in time relative to each other by half of the walking period. The gait period is given by $2\pi/\omega$ where ω is defined as the gait frequency in radians per second (rad/s). Because of the periodic nature of the motion we can formulate joint angles using Fourier series. The Fourier Series of a periodic function of time f(t) can be written as:

$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos\frac{2n\pi}{T} + b_n \sin\frac{2n\pi}{T} t)$$

Where a_n and b_n are constant coefficients and t is the period. The period can be calculated by desired fundamental frequency ω by $t = 2\pi/\omega$. Since the servo motors used in the robot act as low pass filters, we expected to be able to omit higher order frequencies without decreasing performance because these frequencies cannot contribute to the motion that is actually being executed by the robot. Thus we use Truncated Fourier Series (TFS) which have only the 3 first terms of trigonometric form of Fourier series.

$$f(t) = A\left[a_0 + \sum_{n=1}^{m}(a_n \cos\frac{2n\pi}{T} + b_n \sin\frac{2n\pi}{T} t)\right]$$

[1] Zero Moment Point

Where a_n, b_n and t are same as Equation 1, and a is an amplitude scaling parameter used for changing the step length. The parameter m determines the number of terms in the Fourier series. Using this formula significantly reduces the subsequent computational load in the search for feasible and optimal solutions using GA which is discussed in next section. One of the advantages of this approach is that trajectory generation is done directly in the joint space. As such, inverse kinematics computation is not required thus avoiding the singularity problem. The walking rhythm, speed, and walking pattern can also be adjusted online through tuning either a single or two parameters.

2.2 The genetic algorithm

A genetic algorithm was used to search for the optimal values of the coefficients so as to achieve stable walking behavior with desirable characteristics for the robot model. The first 3 terms of the general trigonometric Fourier series were used in the formulations. This is due to the fact that very high frequencies are normally filtered by the joint motors. The frequency of the Fourier series is considered as a constant value and can be changed after the offline learning is finished. This way every Fourier series could be represented by 7 real numbers and as for HOAP-2 model, 25 series are required to define a gait (One for each joint). This makes the size of the individuals large and as a result the learning time gets very long. Therefore, some improvements should be taken into consideration to make the learning process more effective.

Joints of the left part of the robot's body get the same periodic values as the right ones while walking straight, with a delay equal to a period time and there's no need to consider a separate set of Fourier series for the right part in the chromosome structure. This makes the chromosome almost half in size. Besides, the joints in charge of controlling the foot can get their values from the knee and hip joints as they could always be kept parallel to the ground line. Such automatic control of the foot is extremely beneficial in terms of keeping robot's balance, especially in the early stages of the learning phase. Head joints can be also ignored in the gait for the sake of simplicity. With omitting excessive joints, the final chromosome will contain 6 real numbers for every one of the 12 primary joints. Considering this relatively large chromosome size, there are 300 individuals per generation, and 900 generations.

A custom crossover was implemented that consists of a simple two-point crossover together with a creep operator. The creep operator randomly increases or decreases some real values of the chromosome by a very small value between 0 and 5. This crossover was applied with the probability of 0.6 together with a mutation with probability of 0.05. Valid range for the coefficients was also limited to -50 to 50. These values were arrived at after some experimentation. Studying the initial simulation results with different frequencies reveals that almost all of the generated gaits during the learning phase convergence to a human-like walking behavior with similar movement patterns. These similarities include human-like movements of the hand and sinusoidal movements of the waist.

In the initial experiments it was found that some joint trajectories are similar in all of the generated gaits. These common trajectories share the same characteristics and differ in terms of their speed and frequency. For example, the elbow joint bends a little at the start of the walking and stays almost the same during the rest of the movement. Studying these similarities helps to further improve the evolutionary learning process by removing the unnecessary parameters. Experiments show that stable straight walking gaits can be generated by using only two joints of the leg: the hip joint 3 and the knee joint. Based on the initial experiments, the fitness function was also changed in order to achieve better results. In this stage the time factor was ignored for the gaits that keep the robot walking for more than half of the test time. This helps faster gaits to get more fitness value over the stable but slow ones. Furthermore, the average amount of deviation was taken into account so that straight walks have more chance to be selected for regeneration. The simplified model of fitness function is as follows:

if (CurrentTestTime < TotalTestTime / 2) Fitness := Time * Distance

else Fitness := Distance - AverageDeviation

Walking behavior can be adjusted through changing one or two parameters. By changing the Fourier series' frequency and joint movement gain, desired walking speed can be achieved dynamically. In the final experiments we were able to stop the robot after some periods of walking by gradually increasing frequency and decreasing controller's gain. The movement direction can also be determined by the leg joint 1. This joint is responsible for rotating thigh around Z axis. The value of this joint was kept unchanged during the learning process, but it can be slightly modified while walking to make the robot change its direction a few degrees. Fig. 1 shows the simulated robot in Spark simulation environment while walking with maximum speed. This walking mechanism has been published in [9].

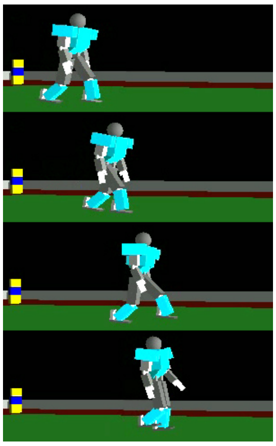

Fig.1 Soccerbot walking skill

3 Kicking skill

After inhibiting the walking behavior and stopping, the robot moves its weight to the non-kicking leg and then shortens the kicking leg, swings it back and accelerates forward. The kicking leg reaches its maximal speed when it comes to the front of the robot. Same principles for keeping robot's balance while walking or running are applied in performing actions like kick or dribble. The effectiveness of using dynamic methods like following the path generated by ZMPs with the help of new control methods like fuzzy PID control is already proved in such fields [10].

4 Goalie dive skill

The goalie is capable of diving into both directions. First, it moves its center of mass and turns its upper body towards the left while shortening the legs. As soon as it tips over its left foot, it starts straightening its body again. While doing so it is sliding on its hands and elbows. These steps are depicted in Fig.2.

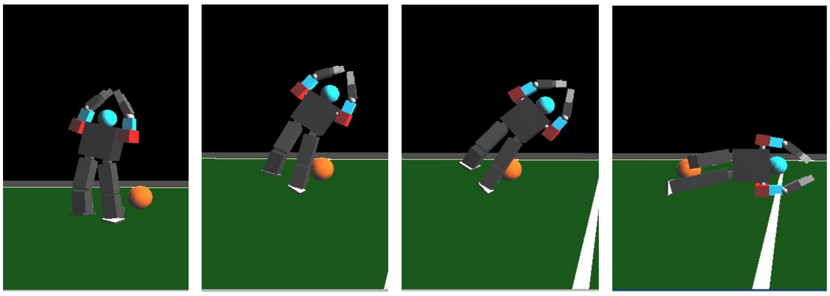

Fig. 2 Soccerbot diving skill

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