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On-line stable gait generation of a two-legged robot using a genetic–fuzzy system

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Abstract

Gait generation for legged vehicles has since long been considered as an area of keen interest by the researchers. Soft computing is an emerging technique, whose utility is more stressed, when the problems are ill-defined, difficult to model and exhibit large scale solution spaces. Gait generation for legged vehicles is a complex task. Therefore, soft computing can be applied to solve it. In this work, gait generation problem of a two-legged robot is modeled using a fuzzy logic controller (FLC), whose rule base is optimized offline, using a genetic algorithm (GA). Two different GA-based approaches (to improve the performance of FLC) are developed and their performances are compared to that of manually constructed FLC. Once optimized, the FLCs will be able to generate dynamically stable gait of the biped. As the CPU-time of the algorithm is found to be only 0.002 s in a P-III PC, the algorithm is suitable for on-line (real-time) implementations.

Keywords: Two-legged robot; Dynamic stability; On-line; Staircase ascending gait; Genetic–fuzzy system

1. Introduction

During locomotion, a legged robot plans both its path as well as gait (the sequence of leg movement) simultaneously. To ensure a statically stable gait of a multi-legged robot, its projected center of gravity (CG) should lie within its support region, which is a convex hull passing through its supporting feet [1]. It is to be noted that a statically stable gait is generally considered for a robot having four or more legs.

A two-legged robot should be dynamically balanced, during which the projected CG of the vehicle may not even lie on the support region. To ensure dynamic stability, a parameter called dynamic stability margin (DSM) is calculated based on the concept of zero moment point (ZMP) [2,3]. The ZMP is a point lying on the ground about which the summation of all moments becomes equal to zero. It represents a

Abbreviations: DSM, dynamic stability margin; FLC, fuzzy logic controller; GA, genetic algorithm; NL, negative large; NS, negative small; PS, positive small; PL, positive large; ZMP, zero moment point

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Nomenclature

d_{ZMP}	distance of zero moment point from the ankle joint
F	ground reaction force
F_N	normal reaction force
F_T	friction force
g	acceleration due to gravity
H	height
L	length
$L_1, \ldots, L_7$	link lengths
t	time step
V_{max}	maximum velocity of the swing leg
s_h	height of the staircase
s_w	width of the staircase
f_s	length of the foot

Greek letters

θ	joint angle
τ	torque

point, at which the ground reaction force is being applied. Mitobe et al. [4] presented an algorithm for controlling the angular momentum of walking robots through the manipulation of zero moment point (ZMP). To achieve a stable motion, the ZMP has to follow a certain trajectory. But, the ZMP may deviate from the prescribed trajectory, due to the disturbances or tracking errors which influence the stability of the robot. Therefore, the deviation of ZMP from the prescribed trajectory has to be compensated. Thus, the ZMP was considered as an actuating signal of the controller and a feedback control law was proposed to control the angular momentum of walking robots.

Seo and Yoon [5] proposed the design of a robust dynamic gait of the biped using the concept of dynamic stability margin. According to them, gait failure occurred because of the discrepancy between the designed and the actual gait motions, which contributed to the changes in body forces. Thus, a gait can be considered to be robust, if it can sustain a fair magnitude of linear impulse applied at the mass center of trunk, in the horizontal direction, for a certain amount of time. So, the minimum magnitude of that linear impulse was defined as the dynamic stability margin and the dynamic gait for a five link planar biped robot was designed by maximizing the dynamic stability margin. A parameter called foot strike time margin, representing the readiness of the foot strike, was also defined by them, which was supposed to have a close positive correlation with the dynamic stability margin. A robust gait with respect to the external disturbances was obtained by maximizing the foot strike time margin.

Goswami [6] solved the problem of robot stability using the concept of foot rotation indicator (FRI) point, which is a point on the foot/ground contact surface, where the net ground reaction force would have to act to keep the foot stationary. To ensure no foot rotation, the FRI point must remain within the convex hull of foot support area. The concept of FRI point was used during single support phase and was generally treated for generating dynamically stable gait.

Although the above methods lay down the foundation of the study of dynamically balanced two-legged robot, they may not be suitable for on-line (real-time) implementations, due to their high computational complexity. Thus, suitable locomotion algorithms (adaptive in nature) are to be developed, which can negotiate unknown terrain also, on-line.

Soft computing is an emerging technique, which consists of fuzzy logic, neural network, genetic algorithm, etc. and their different combinations, can handle real-world complex problems. It has also been used by various researchers, for control of humanoid robots [7]. Some of the works related to real-time control of two-legged robot using soft computing are discussed below.

Capi et al. [8] developed a method based on genetic algorithm to generate a human-like motion. Humanoid robot gait was generated using two different cost functions: minimum consumed energy (CE) and minimum torque change (TC). In real-time situations, the robot has to change its gait according to the conditions of the terrain. But, as genetic algorithm is a time consuming tool, it was used to generate feasible optimal gaits, which were used to teach a radial basis function neural network. The neural network after getting trained was used for real-time gait generation.

Salatian and Zheng [9] carried out gait synthesis for a biped robot climbing sloping surfaces by using a neural network, in which an on-line learning was adopted. They were successful in developing the gait pattern but