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Gait optimization of biped robots based on human motion analysis

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ABSTRACT

This paper proposes a dynamically stable and optimal trajectory generation method for biped robots to walk up and down stairs, based on human motion analysis, since a human walks efficiently without high energy consumption, and the energy-efficient locomotion pattern results in a more natural walking pattern. Seven important elements of the human gait on stairs are identified in the analysis of the motion data captured from subjects. Those factors enable us to generate trajectories of biped robots similar to that of human beings walking up-and-down stairs. The dynamics of the robot and human are different in weight distribution, degree of freedom and so on. A real-coded genetic algorithm as an optimization tool is used to produce the optimized gait for the robot and to improve the energy autonomy and stability. Various computer simulations were performed based on a 12-DOF biped robot model with which many of the essential characteristics of the human walking motion on stairs can be captured. The proposed method exhibits its efficiency in quickly finding an optimal trajectory, which is due to not only the nature of genetic algorithms but also a small number of design variables employed. Thus, this makes it possible to generate various locomotion trajectories of biped robots simply by appropriately changing some of the boundary conditions.

1. Introduction

Biped robots need to have the capability to adapt themselves to artificial environments which include uneven surfaces, stairs, door thresholds, etc., since they should live together with human beings. They also need to carry their own energy source in order to cover a large working area. It is no wonder that lower energy gaits require lighter batteries and in turn make more reduction in weight. It makes them move independently during a long time without supplying additional external power.

One of the most common artificial environments is staircases. Questions which demand our serious consideration with respect to bipedal locomotion on stairs are to minimize their energy consumption and to keep them from falling down to the ground. Research in this direction has been performed by analysis of various human motion patterns, since human beings can make use of gravity effectively and reduce energy consumption. Such energy-minimizing motion looks more natural[1] action.

Ota et al. proposed locomotion patterns for a 8-DOF bipedal robot to move naturally on staircases and on flat ground [6]. However, it is impossible to walk like human beings. Sugahara et al. proposed a tuning-up method for the walking parameters to go up and down stairs for a biped robot with leg mechanisms using the Stewart Platforms [7]. It has been confirmed that the stroke range of use could be reduced by tuning up the waist yaw and preset ZMP trajectories for motion pattern generation. Kwon et al. proposed a method that minimizes consumed energy by analyzing the optimal trajectories for stair walking using the Real-Coded Genetic Algorithm [8]. However, their proposed method takes too much time to find an optimal trajectory because of the use of many design variables, and they only apply the method for the sagittal plane. Park and Choi proposed a method that minimizes consumed energy by searching the optimal location of the mass center of each link using the Real-Coded Genetic Algorithm [9]. However, they do not consider walking trajectory, including the double supporting phase, and their proposed method also takes too much time to find an optimal trajectory because of the use of many design variables.

In this paper, seven key factors in walking up and down stairs are identified by the motion data captured from human beings. Those factors enable us to generate a stair walking trajectory of biped robots similar to that of human beings. As a optimization tool, a real-coded genetic algorithm is employed to obtain the stair optimal trajectory since it is efficient and robust in searching global

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[1] Many studies on human locomotion have suggested that human beings have a strong tendency to walk in a way that minimizes metabolic energy cost [1–3]. Human beings also walk naturally in various environments. In this paper, natural motion means energy minimizing motion of a biped robot walking like a human in various environments [4,5].

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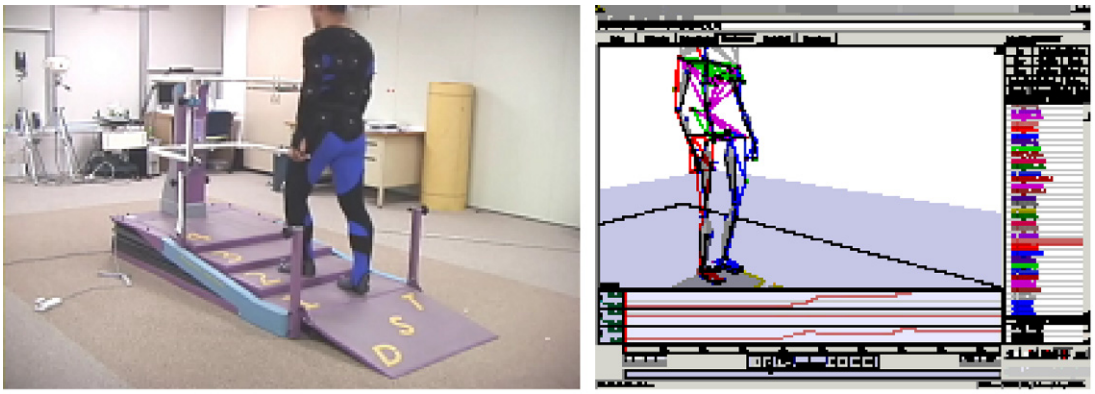
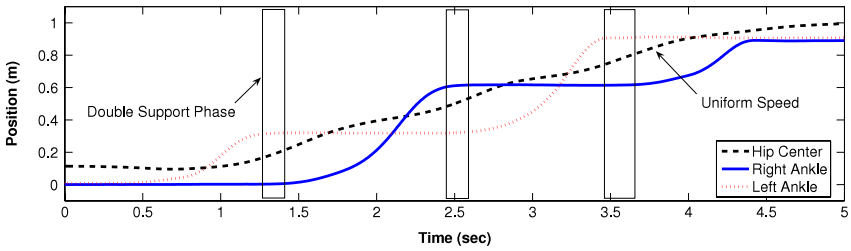
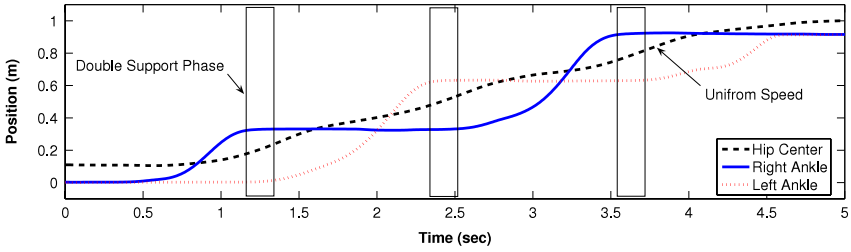


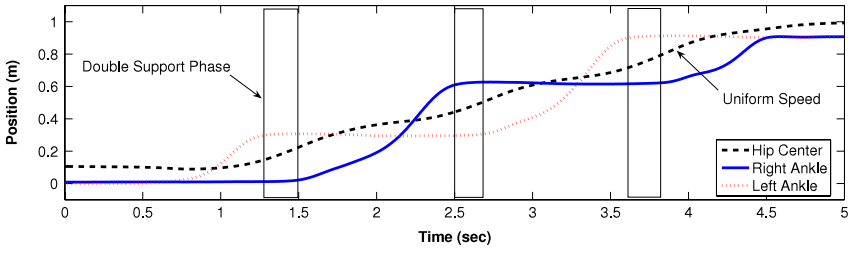
Fig. 1. An image captured from a subject.



(a) Step height: 0.05 m.



(b) Step height: 0.10 m.



(c) Step height: 0.15 m.

Fig. 2. Average data of subjects ascending in the forward direction.

solutions of optimization and also is used due to its simplicity, speed, and ease in dealing with complex constraints [10–12]. The effectiveness of the proposed method is shown in simulations with a 12-DOF biped robot using commercial dynamic simulation software, RecurDyn® [13].

2. Human motion analysis for stair walking

In this paper, a motion analysis system made by Vicon co. was used to acquire and analyze three dimensional data on subjects while walking on stairs. It is composed of 8 cameras [14]. Without loss of generality, the distinguished characteristics of human gaits are obtained using motion data captured from 5 subjects who are male Koreans of similar body weight, 65 kg, and height, 170 cm. The motion data are captured and recorded with 3 trials per subject on average. Fig. 1 shows a captured image from a subject while going up stairs. Figs. 2–7 show motion data walking up and down stairs which have three types of step height such as 0.05, 0.1, and 0.15 m. The subjects are asked to start going up and down stairs from the right or left foot. The hip center (or base link) is the body center coordinate system that moves with the subject.