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An Experimental Analysis of Overcoming Obstacle in Human Walking

Tao Li[1], Marco Ceccarelli[2], Minzhou Luo[1], Med Amine Laribi[3], Said Zeghloul[3]

1. *Institute of Advanced Manufacturing Technology*, *Hefei Institutes of Physical Science*, *Chinese Academy of Sciences*, *Changzhou* 213164, *P. R. China*
2. *Laboratory of Robotics and Mechatronics*, *University of Cassino and South Latium*, *Cassino* 03043, *Italy*
3. *Institute PPRIME - DGMSC*, *CNRS-University of Poitiers - ENSMA*, 15 *Rue de l'Hôtel Dieu*, 86000, *Poitiers*, *France*

Abstract

In this paper, an experimental analysis of overcoming obstacle in human walking is carried out by means of a motion capture system. In the experiment, the lower body of an adult human is divided into seven segments, and three markers are pasted to each segment with the aim to obtain moving trajectory and to calculate joint variation during walking. Moreover, kinematic data in terms of displacement, velocity and acceleration are acquired as well. In addition, ground reaction forces are measured using force sensors. Based on the experimental results, features of overcoming obstacle in human walking are analyzed. Experimental results show that the reason which leads to smooth walking can be identified as that the human has slight movement in the vertical direction during walking; the reason that human locomotion uses gravity effectively can be identified as that feet rotate around the toe joints during toe-off phase aiming at using gravitational potential energy to provide propulsion for swing phase. Furthermore, both normal walking gait and obstacle overcoming gait are characterized in a form that can provide necessary knowledge and useful databases for the implementation of motion planning and gait planning towards overcoming obstacle for humanoid robots.

Keywords: human locomotion, overcoming obstacle, walking gait, biped robot, motion capture

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1 Introduction

In recent years, research works on humanoid robots have been growing rapidly. Human locomotion provides a perfect source of inspiration for the research and development of humanoid robots because nature has solved admirably the problem of biped locomotion during a long time evolution of human beings. In general, human walking has several main characteristics: first, it is fairly smooth because the Center of Gravity (COG) of the upper body has minor motion in the vertical direction; second, it is quite efficient because human beings can make use of gravity effectively[1,2] and the energy that is needed during walking is quite low; and third, it can be considered as optimal for energy consumption[3]. These characteristics are just the desired targets for researchers who are developing humanoid robots.

Since humanoid robots are designed to work in unconstructed environments, researchers have proposed many strategies for biped robots to move in unpredictable environments or on rough terrain[4–6]. Besides, the environments are usually cluttered with unavoidable obstacles, thus the robots should also be able to overcome them. Human beings can know whether we can overpass an obstacle by intuition or experience. However, robots do not have such abilities. Thus, suitable methods should be developed to perform obstacle overcoming for robots. Guan *et al*. analyzed the feasibility for humanoid robots to overcome given obstacles by taking into account the constraints of collision-free, balance and kinematics[7]. However, they just focused on quasi-static stepping over by keeping the projection of the global COG of the robot within the polygon of support, which resulted in somehow unnatural slow motions. Verrelst *et al*. extended the work and proposed fluent dynamic motion using stability criteria on Zero Moment Point (ZMP) instead of COG[8]. Nevertheless, characteristics of human obstacle overcoming behavior have not been taken into account in those works. It is believed that studying obstacle overcoming behavior in

Corresponding author: Marco Ceccarelli
E-mail: ceccarelli@unicas.it

human locomotion will bring us more inspirations for the research and development of robots that can overcome obstacle.

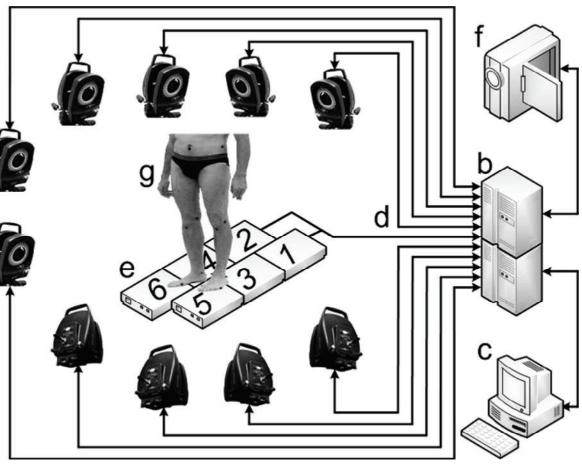
Human locomotion has been widely studied by researchers with the aim to develop humanoid robots[9–13]. In particular, human obstacle overcoming has been widely studied. Draganich and Kuo reported their comparative analysis on the effects of walking speed on obstacle crossing in healthy young and healthy older adults[14]. Krell and Patla analyzed the influence of multiple obstacles in the travel path on avoidance strategy[15]. Chou *et al* investigated motion of the whole body's center of mass when stepping over obstacles of different heights[16]. Lowrey *et al* described age-related changes in avoidance strategies when negotiating single and multiple obstacles in their work[17]. Patla and Vickers studied where and when do we look as we approach and step over an obstacle in the travel path[18]. Later in 2006, Patla and Greig reported their findings believing in that successful obstacle negotiation needs visually guided on-line foot placement regulation during the approach phase[19]. Meanwhile, MacLellan and Patla announced their work on stepping over an obstacle on a compliant travel surface, and revealed adaptive and maladaptive changes in locomotion patterns[20]. These works give an insight view of human obstacle overcoming. However, they were carried out with the aim to provide database for rehabilitation, surgery and psychology. Most of the results cannot be used as reference knowledge for the research and development of biped robots.

The target and originality is to study human locomotion, especially to analyze and characterize human obstacle overcoming, with the aim to provide reference knowledge for the research and development of biped robots. Hence Vicon Nexus[21], which is a commercial motion capture platform, has been used to analyze the operation of overcoming obstacle in human walking. In particular, kinematics of human locomotion in terms of trajectory, velocity, acceleration, and joint variation has been investigated; ground reaction force has been measured; modeling and characterization of both normal walking gait and obstacle overcoming gait have been implemented.

2 An experimental layout

Fig. 1a depicts a scheme of Vicon Nexus motion capture system, which is mainly composed of MX cameras (a), acquisition platform units (b), a PC with Nexus software (c), and MX cables (d). Furthermore, with the aim to measure ground reaction force, six force plates (e: 1–6) are used. The force plates are the products of KISTLER Ltd., which have extremely wide measuring range, excellent measuring accuracy, high natural frequency, versatility, and threshold F_z <50 mN. Furthermore, this force plate is designed specifically for use in basic research, sports and gait analysis. The plate can be mounted in any position. Moreover, a video recorder (f) is used in the system to record the process of the experiment. In addition, an experimental subject with markers is essential (g). Using Nexus software, x, y and z coordinates of each marker at each moment are recorded in a reference coordinates frame.

Fig. 1b shows an experimental setup according to Fig. 1a. In the experiment, 10 MX cameras were used to achieve quite accurate results. In the middle part of the walking platform, 6 force sensors, which can provide 6D interaction wrench measurements, were installed for



(a)

(b)

Fig. 1 A scheme of Vicon Nexus[13]: (a) a-10 MX cameras; b-acquisition platform units; c-PC with Nexus software; d-MX cables; e-6 force plates; f-classical camera recorder; g-subject with markers; (b) an experimental setup of the motion capture system.