Biped Passive Dynamic Walking: A Review

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Abstract

This paper mainly focuses on the mobile biped robots. It introduces the passive dynamic walking model, the landmark passive dynamic walking robot without knees, review of the development of passive walking robots. and the XZ-01 designed by CUPT, which has broken the Guinness World Records.

Keywords

Biped Robot, Passive Dynamic Walking, XZ-01.

1. Introduction

As the expansion of human activities, mobile robots have been a high speed development and widespread applications in scientific investigation, space exploration and military fields. Mobile robots have become the indispensable important tool for humans. According to different application environment, the movement pattern adopts generally including wheeled mobile robots, caterpillar, bionic foot type, hybrid-type and some methods. In the last decade there has been much progress in the field of biped walking robots. Previous biped robots with human-like forms have demonstrated versatile functions and actions [1-4]. HONDA's ASIMO is often used as a benchmark of humanoid robots which can walk on flat terrain by using predictive motion control, and also realized well movement ability: up-down of stairs, turning, and dancing [5]. These robots are under-achieving in terms of efficiency, disturbance handling, and natural appearance compared to human walking [6]. Since a lot autonomous humanoid robots have been actually made, human gait analysis is indispensable,and they are not practicable because they cannot move for a long period with battery [7]. In this paper, we introduce a robot walking method named Passive Dynamic Walking(PDW), which is a gait developed, partially or in whole, by the energy provided by gravity [8]. The rest of this paper is organized as follows: Section 2 retrospects the dynamic model of the PDW; Section 3 reviews the well-known PDW robots in the world and Section 4 draws conclusions.

2. Passive dynamic walking model

In 1990, McGeer proposed a class of two-legged machines, which can walk down stability along the gentle slope without any motor or controller[8]. More and more researchers have realized that PDW could be the most efficient mechanism in humanlike locomotion. Here, we will use the simplest walking model by Garcia et al.(Fig.1).The 2D model which irreducibly simple, point-foot straight-legged has a typical walking step. Just after footstrike the swing leg swings forward to past the stance leg until the swing leg hits the ground and a new step begins. Then they observed that as the angle of slope increased, the stable period-1 gait bifurcated into period-2 gait, then period-2 gait divided into period-4 and ultimately into chaos gaits [9-10].Goswami and coworkers were the first researches who investigated the chaos and bifurcation in a passive walking model named 'compass-gait biped', as shown in Fig.2.

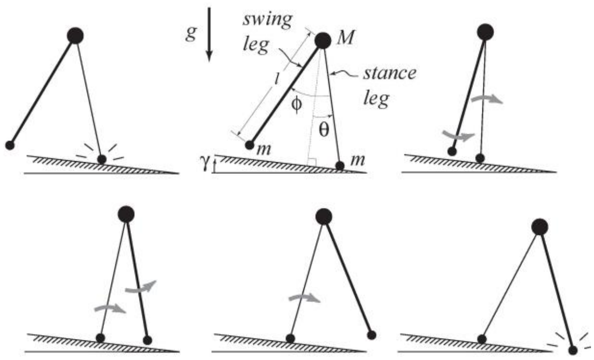

Fig. 1 A typical simplest passive walking step. θ is the angle between the stance leg and the slope normal, ϕ is the angle between the two legs, l is the length of the leg while M is the hip mass, m is the mass of the foot, g is the gravitational acceleration and ϕ is the lope angle [11]. Adapted from Garcia et al.

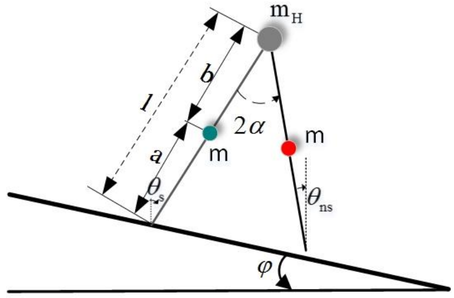

Fig. 2 Model of a compass gait biped robot on a slope. The robot consist of two knee-less legs, each having a joint mass and a third point mass coincides with the hip joint [12].

H.Gritli et al. researched on the PDW model of Berman and explored that the Garcia et al. which is a two-degrees-of freedom dynamic system that possesses periodic as well as chaotic gaits in a given set of parameters (see Fig.3(a)). By giving bifurcation diagrams and Floquet multipliers, they showed that depending on initial conditions, new passive walking pattern can be observed and a pair of stable and unstable period gait patterns is generated though a cyclicfold bifurcation [13]. Then the stable period-three orbit generates a route to chaos (see Fig.3(b)).

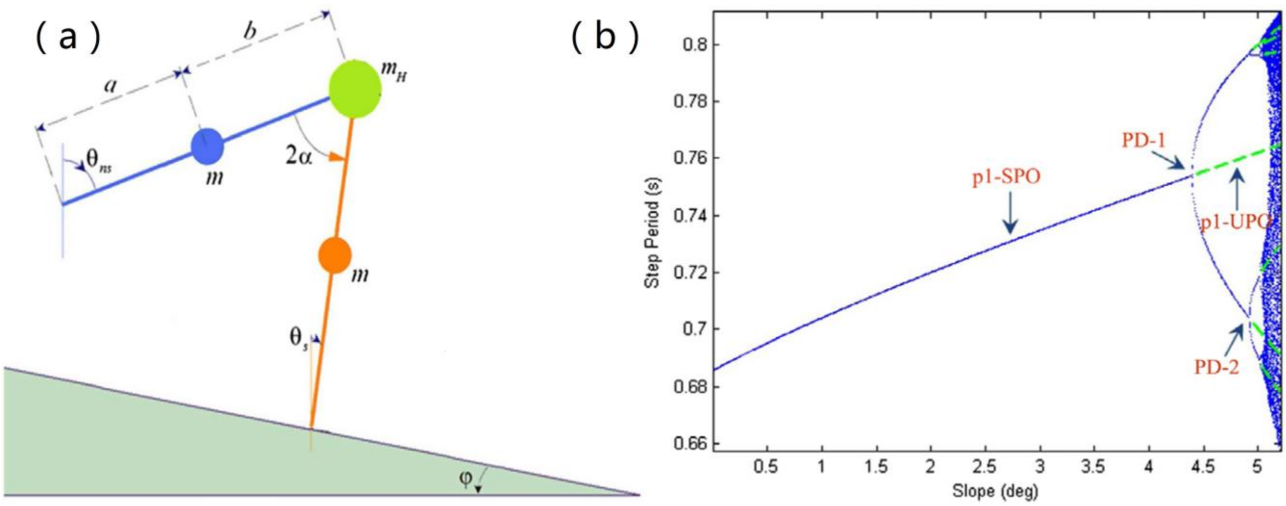

Fig. 3 Model of compass-like biped model (a) and its bifurcation diagram (b) [13]

3. The progress and prospect of passive walking

Traditional robots mostly adopt the static walking theory while ZMP (Zero Moment Point)-based control is the most commonly used in active walking control method. On the contrary the PDW robots adopted the dynamic walking. Over the last decades, the researchers have developed a batch of famous passive or quasi-passive dynamic walking robot. McGeer conducted a passive bipedal machine-Dynamite. At the Delft Bio robotics Laboratory (DBL) various biped robots are studied to get a better understanding of how humans walk. Delft developed the 3D robot driven by artificial pneumatic muscle-Denise(Fig.4), considering the freedom of lateral movement in 2005 [14].As shown in Fig.4, it makes full use of the walking state ”forward” to adjust balance in the walking process and improve the stability of the gait. It is the most successful application in human walking robot mechanism design cased which achieves the 3D passive walking. The biped robot Flame which shown in Fig.4 is designed for walking, where it is not locally stable but the whole walking motion is stable [15]. This is the difference with the trajectory controlled biped robots and the design of Flame makes it challenging to develop a stable gait initiation procedure. The goal of DBL is to develop a humanoid robot with low energy consumption, high versatility and the ability to deal with large disturbance [16].

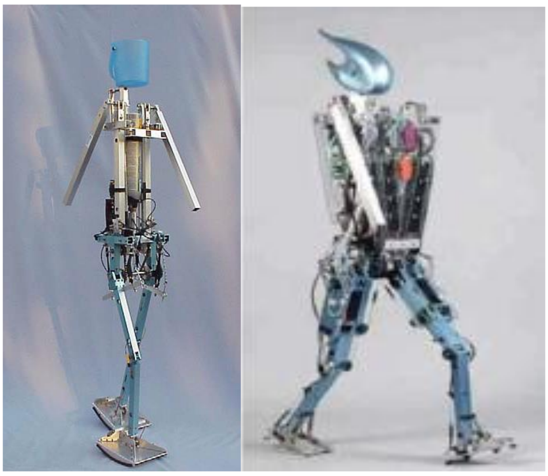

Fig. 4 Delft's Denise and Flame [14, 15]

In addition, Leo was designed in 2009 by Delft which is able to realized completely independent walking and can stand up only relies on its arms and legs when fall down (see Fig.5). Passive walking is more personification on the function and it will be a further step. Cornell University invented Ranger and Cornell powered biped [18]. Ranger was steered with a model plane remote control that controlled a small motor which twisted the inner pair of legs (Fig.6). The coordination of the walking was operated by the 6 onboard microprocessors. Ranger has small rounded feet and at each step it falls and catches itself in a controlled manner. Ranger walked 65.2km in 186,076 steps in about 31 hours without being touched by a human with a cost of transport [COT=Used energy/(Weight*Distance travel)]of 0.255,similar to human's COT of 0.2[19].And Ranger set a record of the farthest distance covered by a quadruped robot[20].

Fig. 6 Cornell University's passive dynamic walker-Ranger.

Fig. 7 Chongqing University of Post and Telecommunication's XZ-01.

However, nowadays multiple attentions have been paid on the robot locomotion nowadays when the XZ-01 made by CUPT that broke the Guinness World Records made by Cornell in 2010(Fig.7). XZ-01 (XingZhe) is one of the most energy efficient robots in the world which can go straight, turn around, up and down the gentle slope. XZ-01 mimics the mechanism of walking, and keeps balance dynamically with its natural gaits like a human. Compared with active robot, although the PDW is more efficient, domestic passive walking prototype experiment is less than fully developed drive robot. It has a development space in prototype and experimental research, as well as the processing to improve the passive walking prototype by knee joint configurations.

4. The progress and prospect of passive walking

Foot-type mobile robot has a unique advantage of higher flexibility, which can be easily integrated into working together with humans. In order to accomplish these kinds of robot and put them into practical use, there are quite many unsolved problems. To attain perfection, a lot of researches are developing on other aspects like interfaces, artificial intelligence, cognitive engineering and motion control. We anticipate that this will accelerate the development of humanoid robots, which will have a potential application.

Acknowledgements

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References

[1] Bongsob Song and J. Karl Hedrick. Biped Robot Control. Springer London, 2011.

[2] C E Bauby, A D Kuo, C E Bauby, and A D Kuo. Active control of lateral balance in human walking - journal of biomechanics. Journal of Biomechanics, 33(11):1433C1440, 2000.

[3] MIN-SU KIM and JUN HO OH. Posture control of a humanoid robot with a compliant ankle joint. International Journal of Humanoid Robotics, 7(1):5–29, 2011.

[4] Spyros G. Tzafestas, Thanassis E. Krikochoritis, and Costas S. Tzafestas. Robust sliding-mode control of nine-link biped robot walking. Journal of Intelligent & Robotic Systems, 20(2-4): 375–402, 1997.

[5] R. Watanabe, C. Aoyama, and S. Matsunaga. The intelligent asimo: system overview and integration. In IEEECRSJ International Conference on Intelligent Robots and Systems, Vol. 3, pages 2478 – 2483, 2002.

[6] Daan G.E. Hobbelen and Martijn Wisse. Limit cycle walking. Mechanical Maritimes & Materials Engineering, 8215(2):3132 – 3137, 2007.

[7] Toshio Fukuda, Yasuhisa Hasegawa, Kosuke Sekiyama, and Tadayoshi Aoyama. Multi-locomotion Robotic Systems: New Concepts of Bio-inspired Robotics, volume 81. Springer, 2012.

[8] Tad Mcgeer. Passive dynamic walking. International Journal of Robotics Research, 9(6):62–82, 1990.

[9] Mariano Sylvio Garcia. Stability, scaling, and chaos in passive-dynamic gait models. Dissertation Abstracts International, Volume: 59-12, Section: B, page: 6373, 1999.

[10] Mariano Garcia and Anindya Chatterjee & Andy Ruina. Efficiency, speed, and scaling of two-dimensional passive dynamic walking. Dynamics & Stability of Systems, volume15 (2):75–99, 2000.

[11] M Garcia, A Chatterjee, A Ruina, and M Coleman. The simplest walking model: stability, complexity, and scaling. Journal of Biomechanical Engineering, 120(2):281–288, 1998.

[12] Ambarish Goswami, Benoit Thuilot, and Bernard Espiau. Compass-like biped robot – part i: Stability and bifurcation of passive gaits. Other, 1996.

[13] Hassne Gritli, Nahla Khraief, and Safya Belghith. Period three route to chaos induced by a cyclic-fold bifurcation in passive dynamic walking of a compass-gait biped robot. Communications in Nonlinear Science & Numerical Simulations, 17(11):4356–4372, 2012.

[14] Martjin Wisse and Richard Q Van der Linde. Delft pneumatic bipeds, volume 34. Springer Science & Business Media, 2007.

[15] JM Truffino. Gait initiation for a biped robot. PhD thesis, TU Delft, Delft University of Technology, 2009.

[16] Martijn Wisse, D. G. E. Hobbelen, R. J. J. Rotteveel, S. O. Anderson, and G. J. Zeglin. Ankle springs instead of arc-shaped feet for passive dynamic walkers. In Humanoid Robots, 2006 6th IEEE-RAS International Conference on, pages 110–116, 2007.

[17] Erik Schuitema, Martijn Wisse, Thijs Ramakers, and Pieter Jonker. The design of leo: a 2d bipedal walking robot for online autonomous reinforcement learning. In Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on, pages 3238–3243. IEEE, 2010.

[18] Steven H Collins, Martijn Wisse, and Andy Ruina. A threedimensional passive-dynamic walking robot with two legs and knees. The International Journal of Robotics Research, 20(7):607–615, 2001.

[19] Pranav Bhounsule, Jason Cortell, and Andy Ruina. Design and control of ranger: an energy-efficient, dynamic walking robot. Proc Clawar, pages 441–448, 2012.

[20] Pranav A. Bhounsule, Jason Cortell, Anoop Grewal, Bram Hendriksen, J. G. Dani& Karssen, Chandana Paul, and Andy Ruina. Low-bandwidth reflex-based control for lower power walking: 65 km on a single battery charge. International Journal of Robotics Research, 33(10):1305–1321, 2014.