Design of a Legged Walking Robot with Adjustable Parameters

Y. Zhang, V. Arakelian and J.-P. Le Baron

Abstract In the past decades, an extensive research has been focused on legged walking robots. One of the most attractive trends in the design of walking robots is the development of biped robots with reduced number of degrees of freedom. This paper deals with a new solution of a legged walking mechanism with reduced number of degrees of freedom. It consists of a driven cam system mounted on the body frame and connected with feet via pantograph mechanisms. The introduced adjustable parameters allow one to generate two different steps with variable heights as well as allow the robot to climb stairs. The efficiency of the suggested design principle of the legged walking robot is illustrated by numerical simulations carried out via ADAMS software.

Keywords Mechanism design · Walking robot · Pantograph-leg mechanism · Mechanism with adjustable parameters

1 Introduction

It is well known that legged locomotion is more efficient, speedy, and versatile than the one by track and wheeled vehicles when it operates on a rough terrain, steeps, stairs or avoid obstacles. This research field has attracted great interest of many research groups and companies in the past few decades.

The pioneering works in the field of legged robots were achieved around 1970 by two famous researchers, Kato [1–3] and Vukobratovic [4, 5]. Both works were characterized by the design of relevant experimental systems. In Japan, the first

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J. Beran et al. (eds.), *Advances in Mechanism Design II*,
Mechanisms and Machine Science 44, DOI 10.1007/978-3-319-44087-3_9

anthropomorphic robot, WABOT 1, was demonstrated in 1973 at Waseda University. In Yugoslavia, Belgrade, at the Mihailo Puppin Institute, Miomir Vukobratovic and his team designed the first active exoskeletons and several other devices. In the next decade, the breakthroughs came from the United States [6–9]. Simultaneously, Robert McGhee and Kenneth Waldron, achieved the design of a quasi-industrial system able to walk on natural irregular terrain, which was driven by a human [10, 11]. The idea of studying purely passive mechanical systems was proposed by McGeer [12]. In this paper, McGeer has showed that there exists a class of two-legged machines for which walking is a natural dynamic mode: once started on a shallow slope, such a machine will settle into a steady gait quite comparable to human walking, without active control or energy input. Several researchers have followed the tracks open by Tad McGeer.

The end of the millennium was a period of intense technological activities. Industrial breakthroughs showed to the world that building true humanoids was now possible. In Japan, the first humanoid robot, P2, was exhibited by Honda in 1996, followed by several more: ASIMO (Honda), QRIO (Sony), HRP (Kawada), etc.

To create biped robots walking like a human is necessary to use a large number of actuators. Therefore, these robots are automorphic and flexible. However, there are several drawbacks: complexities of the design and the control system, low energy efficiency due to the masses of motors, as well as an overly high price complicating practical use.

To make a biped robot more attractive, a different methodology can be considered such as constructing a biped robot with reduced number of degrees of freedom [11–15]. In the last decade, at the Laboratory of Robotics and Mechatronics in Cassino University, Marco Ceccarelli and his team have proposed various solutions for Low-Cost Easy-Operation leg design [16–18]. The Chebichev four-bar linkage has been successively used for generation a foot trajectory. In order to amplify the produced motion of the Chebyshev linkage, a pantograph mechanism has been utilized.

This paper is organized as follows. In the first section the leg mechanism is introduced as consisting of a cam mechanism and a pantograph mechanism. Then, the kinematic synthesis of legs is discussed. Finally, the results of numerical simulations are provided.

2 Mechanism Design

The typical walk consists of a repeated gait cycle. The cycle itself contains two phases: a propelling phase and non-propelling phase [18]. In Fig. 1, the thicker line represents the supporting leg (right leg) in propelling phase and the thin line represents the swing leg (left leg) in non-propelling phase. It is known that for design a one-DOF leg mechanism with back-forth and up-down motion capability, the foot point should generate an ovoid curve, which is composed of a straight-line segment and a curved segment (see Fig. 1). The straight-line segment is related to the propelling phase when the corresponding leg touches the ground and could guarantee

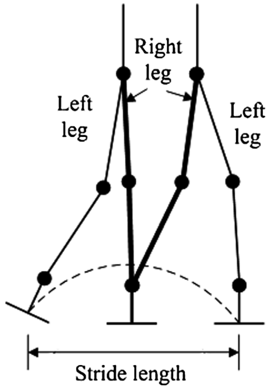


Fig. 1 Two-stage step cycle for human walking gait

stable propelling of the body. The curved segment is related to the non-propelling phase, which is produced by leg when it swings from back to forth [18].

Such a trajectory can be produced by various linkages (Watt, Evans, Chebichev, etc.).

However, these linkages produce only one type of steps with a constant length and height. In addition, in many cases, they provide walking motion only on a horizontal surface.

Therefore, in this paper the proposed one-DOF leg mechanism consists of a cam mechanism with variable angle of inclination connected with a pantograph mechanism permitting to amplify the input motion.

Two adjustable parameters are included in the proposed walking robot: an angle of inclination of the cam mechanism permitting the robot to climb stairs and a pantograph mechanism having the possible to be fixed in two different axes.

Figure 2 shows motions of the proposed leg mechanism with two different points of fixation. As seen from Fig. 2a, b, for the same input trajectories of the point C of the cam mechanism two output trajectories are produced.

The pantograph mechanism is used to amplify the input trajectory of the point C into output trajectory with the same shape of point A. In the suggested design concept, the fixed point can be either B_1 or B_2. Changing the position of the fixed point $B_i\ (i = 1 \text{ or } 2)$ on the body frame allows one to obtain two output trajectories with different magnitudes. The amplified ratio of the pantograph mechanism depends on the length of links.

For the first case shown in Fig. 2a, the amplify ratio is $k_1 = B_1A/B_1C$ and for the second case shown in Fig. 2b, the amplify ratio is $k_2 = B_2A/B_2C$. Thus, given the need of walking, two different possible steps can be produced with small or large stride length. The choice of adjustable parameters $B_i\ (i = 1 \text{ or } 2)$ can be carried out taking into account the size of the obstacles and the imposed speed of walking.

The second adjustable parameter is the angle of inclination of the cam mechanism. The rotation of the axis a-a of the cam mechanism at an angle of α (Fig. 3)

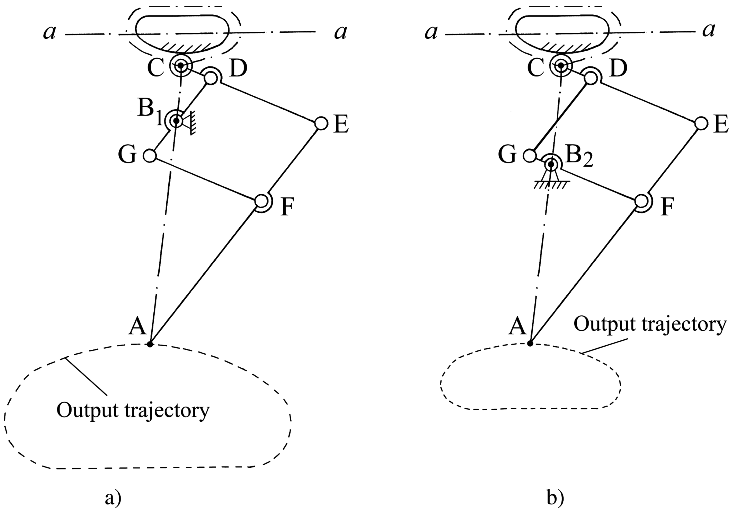
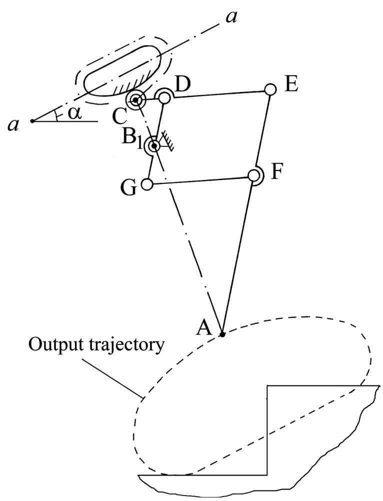


Fig. 2 Leg mechanism with two output trajectories

Fig. 3 Leg mechanism with rotated input cam mechanism



allows one to change the orientation of the input trajectory. Such an adjustment allows the walking robot to climb stairs.

The value of the angle α depends on the stair's parameters (height and width). Based on the stair's parameters, the walking robot can be adjusted with inclination angle α as well as with small or large stride length.

To illustrate the efficiency of the suggested walking robot let us consider CAD simulations carried out via ADAMSA software.

3 Numerical Simulations

The CAD model of the legged walking robot was created by CATIA and it was then imported to ADAMS. For the pantograph mechanism, when B_1 is the fixed point, the amplify ratio was 4, and when B_2 is the fixed point, the amplify ratio was 1.

The first two simulations were performed when the robot was walking on the plain road and the fixed point of pantograph mechanism was on B_1 or B_2 respectively. The two motions were inputted on each side of the rolling bars with a speed of 36°/s. The power consumption of input motion during leg's stand phase and swing phase are shown in Figs. 4 and 5.

The second two simulations were performed when the robot was climbing stairs. The two motions were executed on each side of the rolling bars with a speed of 36°/s, the angle between two cams and main body of the robot was adjusted to 20°. Figures 6 and 7 show the power consumption of input motion during leg's stand phase and swing phase.

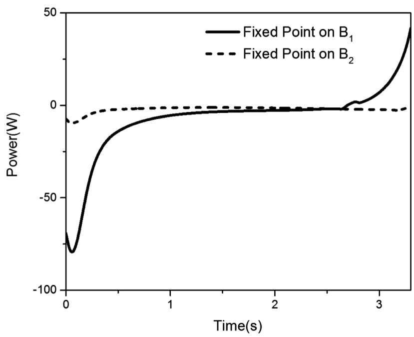


Fig. 4 Power consumption of input motion during leg's stand phase when fixed point on B_1 and B_2

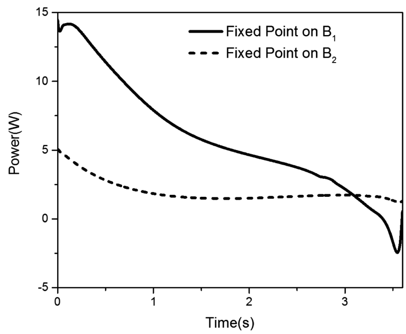


Fig. 5 Power consumption of input motion during leg's swing phase when fixed point on B_1 and B_2

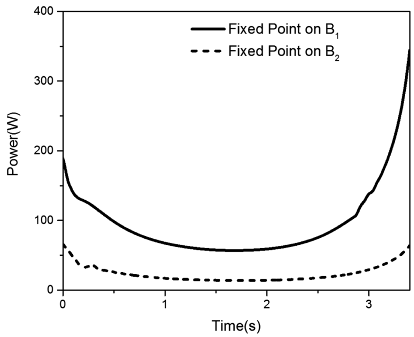


Fig. 6 Power consumption of input motion during leg's stand phase when fixed point on B_1 and B_2

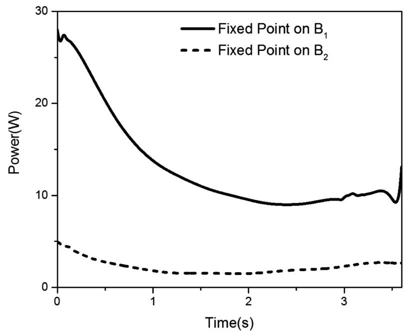


Fig. 7 Power consumption of input motion during leg's swing phase when fixed point on B_1 and B_2

4 Conclusions

In this paper, a one-DOF legged walking robot based on pantograph mechanisms with adjustable parameter is proposed. The introduced adjustable parameters allow one to generate two different steps with variable heights as well as allow the robot to climb stairs. Simulation results showed that the change of fixed point position of pantograph mechanism can significantly change the speeds of walking and climbing stairs, and it also can change the power consumption as well. It means the proposed robot can change its speed and switch to "save energy mode" in some circumstances. On the other hand, the variation of the angle between cams and main body can let the robot be able to climb stairs, and the angle can be adjusted to adapt the slope of stairs. Finally, it is important to note that in the proposed design concept a special attention should be given to the determination of the pressure angle in cam mechanisms to ensure smooth motion.

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