2005년도 정보 및 제어 학술대회(CICS 05) 논문집

9 링크 이족로봇의 부드러운 걸음새 경로 계획

A Smoothed Gait Trajectory Planning of a 9-link Biped Robot

김 철 하*, 유 성 진**, 최 윤 호*, 박 진 배**, 곽 기 석**
(Chul Ha Kim, Sung Jin Yoo, Yoon Ho Choi, Jin Bae Park, Kwak Ki Seok)

Abstract - We propose an analytic trajectory planning method using a wavelet neural network (WNN) for a natural and stable locomotion of the 9-link biped robot. We design a appropriate locomotion, which have a kick-action, by means of a ballastic walking model condition. In this paper, a WNN is used to interpolate the trajectory planed by the analytic method. Finally, we show the proposed trajectories through the computer simulation.

Key Words : 9-link Biped Robot, Gait Trajectory Planning, Wavelet Neural Network.

1. Introduction

A planning of a gait trajectory is an important problem for a anthropomorphic and stable locomotion of the 9-link biped robot.

In past several years, many researches have been done for describing a walking model. One of them is the usage of experimental kinematic data and another is an analysis of the walking model. Due to the complexity of the human musculo-skeletal system, an analytical model research is scarcely attempted. One hypothesis among the analytical models suggests that a gait should be performed in a way that requires the least expenditure of energy and the walking model behaves like the coupled links in a compound pendulum. Mochon [1] developed mathematical models for least expenditure of walking energy under ballastic condition.

On the other hand, recently, wavelet neural networks (WNNs), which combine the learning of neural network and the advantages of the wavelet decomposition, are proposed and used as a good estimation tool for the identification [2].

In our 9-link biped robot model [3], the proposed gait trajectory is generated on the basis of a ballistic model condition in the single support phase. In this paper, we design a anthropomorphic gait trajectory considering heels and toes. And WNN is used to interpolate the trajectory planed by the analytic method

2. Trajectory Planning of 9-link Biped Robot

2.1 Walking on a horizontal plane surface.

The planning of the biped walking is composed of three parts. First part is from the vertical position to a starting step, second part is from a starting step to a steady walking and third part is a steady walking. We propose a locomotion like a human walking according to ballistic model conditions. The 9-link biped robot model used in this paper is shown in Fig. 1 [3].

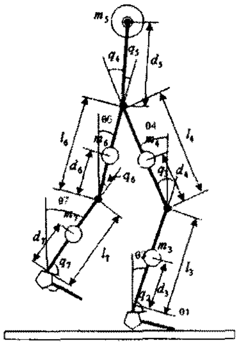

Fig.1. 9-link biped robot model

In this model, each of relative joint angles ($q_1 \cdots q_8$) is designed to plan a appropriate trajectory. Since the 9-link biped robot has heels and toes in comparison with a 5-link biped robot, the locomotion of a 9-link biped robot needs the kick action. This action has the following advantages. First, a kick action reduces the up and down movement of the body. Second, a kick-action can give the

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저자 소개
*延世大學校 電氣電子學科 碩士課程
**延世大學校 電氣電子學科 博士課程
***京畿大學校 電子工學部 敎授
****延世大學校 電氣電子學科 敎授

※ 이 논문은 2004년도 한국학술진흥재단의 지원에 의하여 연구되었음(KRF-2004-041-D00261)

radial velocity to the robot system. Then, the loss of angular momentum at leg-support exchange can be decreased. Third, a kick-action using a toe realizes the natural walking like the human walking.

2.1.1 Trajectory planning of a starting step from the vertical position

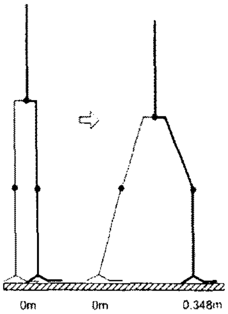


Fig. 2 Starting step.

Description of walking from the vertical position to a starting step (left leg moving) is shown in Fig. 2. From the vertical position where the two legs are aligned together, the biped robot lifts up the left leg with the right leg serving as the support. And the right toe elevates before the collision between the ground and the left leg. The right support leg depends on a toe angle $q_{r_1}(t)$, an ankle angle $q_{r_2}(t)$, and a knee angle $q_{r_3}(t)$. The trunk motion depends on $q_{r_4}(t)$. The left swinging leg depends on a shin angle $q_{r_5}(t)$, a knee angle $q_{r_6}(t)$, an ankle angle $q_{r_7}(t)$, and a toe angle $q_{r_8}(t)$.

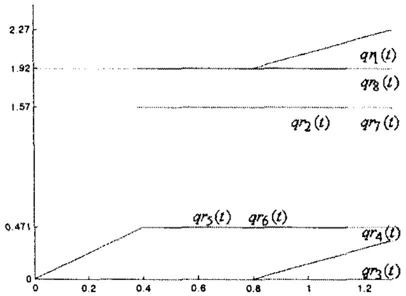


Fig. 3 Trajectory of starting step.

At the first step (0-1.3) shown in Fig. 3, the first step consist of non-kick phase(0-0.8) and kick phase(0.8-1.3). The signal $q_{r_1}(t)$ is selected to be 110° ($q_{r_1}(t)=1.92$ rads) during non-kick phase and 130°($q_{r_1}(t)=2.27$) during the kick phase. The ankle angle is selected to be 90°($q_{r_2}(t)=1.57$), and the signal $q_{r_3}(t)$ of the knee joint of the supporting leg is kept to be zero. Since the trunk is always upright, an absolute angle of trunk is zero. So, the signal $q_{r_4}(t)$ is expressed as $q_{r_4}(t)=-q_{r_3}(t)-q_{r_2}(t)+q_{r_1}(t)-90^\circ+\varepsilon-\theta_1(t)$ (θ_1, ε constant value in [3]). The signals $q_{r_5}(t)$ and $q_{r_6}(t)$ play a significant role for stable walking. Because the knee joint of a swing leg must be kept in the bending state, the signal $q_{r_5}(t)$ and $q_{r_6}(t)$ are selected to be 27° ($q_{r_5}(t)=0.471$) and 27°($q_{r_6}(t)=0.471$ rads). To support a foot, an ankle angle is selected to 90°($q_{r_7}(t)=1.57$). A foot joint signal $q_{r_8}(t)$ is the same as $q_{r_1}(t)$ in non-kick phase.

2.1.2 Trajectory planning of a steady walking

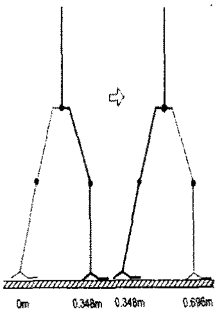


Fig.4 Steady walking.

Description of a steady walking (right leg moving) is shown in Fig. 5. From the position where the right leg is backward and the left leg is forward, the biped robot lifts up the right leg with the left leg serving as the support. And the left toe elevates before the collision between the ground and the right leg. The left support leg depends on a toe angle $q_{r_1}(t)$, an ankle angle $q_{r_2}(t)$, and a knee angle $q_{r_3}(t)$. The trunk motion angle depends on $q_{r_6}(t)$. The right swinging leg depends on a shin angle $-q_{r_4}(t)$, a knee angle $-q_{r_5}(t)$, an ankle angle $q_{r_7}(t)$, a toe angle $q_{r_8}(t)$.

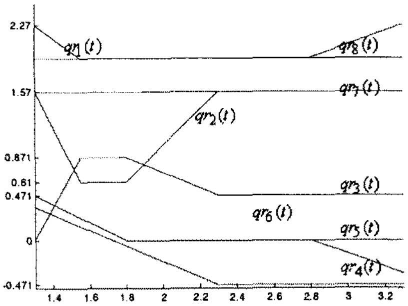


Fig.5.Trajectory of a steady walking(left leg

At the second step (1.3-3.3) shown in Fig. 5, the kick phase is done during (2.8-3.3) seconds. The signal $q_{r_1}(t)$ is selected to be 110°($q_{r_1}(t)=1.92$) like the first step. The signal $q_{r_2}(t)$ is selected from 90° ($q_{r_2}(t)=1.57$ rads) at 1.3 second to 35°($q_{r_2}(t)=0.61$) at 1.8 second during the gait change(1.3-1.8). The signal $q_{r_3}(t)$ of the knee joint is selected from 50°($q_{r_3}(t)=0.871$ rads) at 1.3 second to 27° ($q_{r_3}(t)=0.471$ rads) at 1.8 second during a gait change. Due to gait change, each of $q_{r_4}(t)$, $q_{r_5}(t)$, and $q_{r_6}(t)$ is substituted for $q_{r_6}(t)$, $-q_{r_4}(t)$, and $-q_{r_5}(t)$. So, $q_{r_6}(t)$ refers to trunk motion and designed like the first step. The signal $q_{r_4}(t)$ and $q_{r_5}(t)$ are determined like the first step. So, each of the signal $q_{r_4}(t)$ and $q_{r_5}(t)$ are selected from 27°($q_{r_4}(t)=0.471$ rads) at 1.3 second to 0° at 1.8 second and from 27°($q_{r_5}(t)=0.471$ rads) at 1.3 second to 0° at 1.8 second during gait change. Since an ankle joint angle $q_{r_7}(t)$ should support the left leg, the ankle angle is selected to 90°($q_{r_7}(t)=1.57$). The signal $q_{r_8}(t)$ is selected to be 110° ($q_{r_8}(t)=1.92$ rads) and 130°($q_{r_8}(t)=2.27$) during the kick phase.

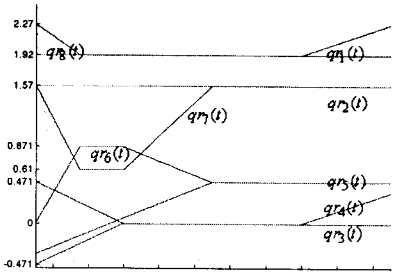


Fig.6. Trajectory of a steady walking(right

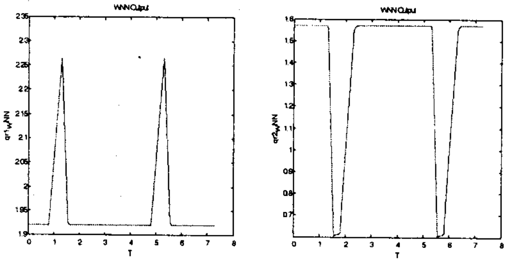
At third step (3.3-5.2), the joint angle trajectory is similar with the second step. From the position where the left leg is backward and the right leg is forward, the biped robot lifts up the left leg with the right leg serving as the support. And the right toe elevates before the collision between the ground and the left leg. The right support leg depends on a toe angle $q_{r1}(t)$, an ankle angle $q_{r2}(t)$, and a knee angle $q_{r3}(t)$. The trunk motion angle depends on $q_{r4}(t)$. The left swinging leg depends on a shin angle $q_{r5}(t)$, a knee angle $q_{r6}(t)$, an ankle angle $q_{r7}(t)$, and a toe angle $q_{r8}(t)$.

2.2 Planning of smooth trajectory using a wavelet neural network

Every joint angle trajectory is composed of combination of line segments. These joint angle trajectories have a problem that a joint angle varies rapidly and lots of torque is needed for rapid angle change at the end point of line segment. Solving these problems, we use a wavelet neural network (WNN) which consists of a continuous function to smooth bent parts of coupling points of line segments. In addition, the smoothed bending joint angle can generate the smooth locomotion. We find the stable and appropriate locomotion by adjusting learning rate of a WNN.

3. Simulations

We interpolate each of trajectory using a WNN. The weight parameters of the WNN are randomly selected and each of learning rate is chosen as a good performance balanced with bending rate. Fig. 7 shows smoothed trajectories interpolated using WNNs. Fig. 8 shows a stick diagram using proposed trajectories.



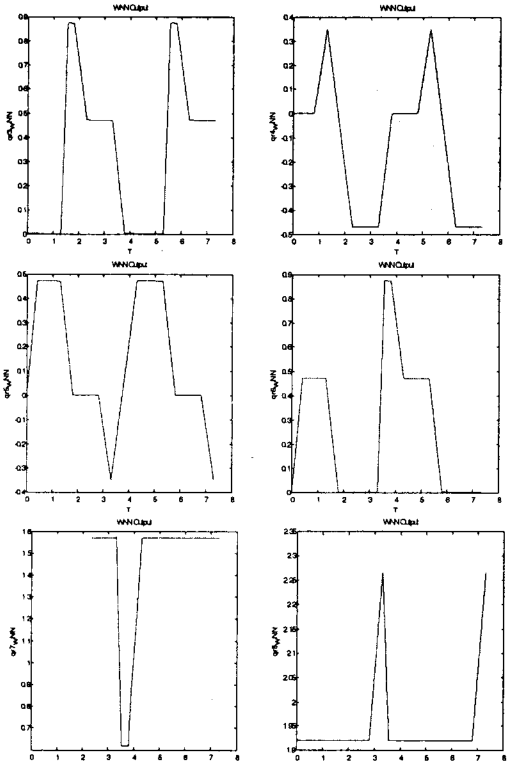


Fig. 7 A smoothed trajectory using WNNs.

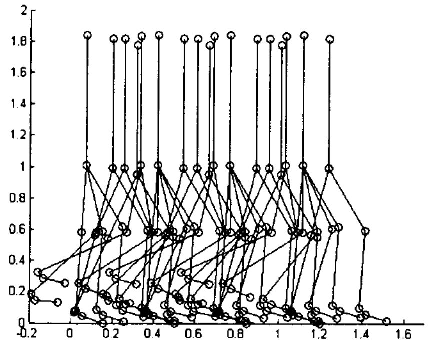


Fig. 8 Locomotion using proposed trajectories.

4. Conclusion

We have designed a appropriate locomotion, which have a kick-action, by means of a ballastic walking model condition. And a WNN has been used to interpolate the trajectory planed by the analytic method.

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